DEVELOPING A LEAN ENABLERS TRAINING PROGRAM USING VIRTUAL REALITY (VR) SYSTEM

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Abstract

Training plays a major role in improving work within organisations by ensuring that the appropriate level of knowledge and skills are shared among personnel. It moulds the thinking process and leads to quality performance. However, training which includes a practical aspect usually targets a specific type of trainee and can limit the learning of an individual coming from a different background than that taken into consideration when the training programme was originally developed. This research focuses on training, and attempts to develop a program using a virtual reality (VR) system as a platform to create a simulated working environment which has the flexibility to train staff members of an organisation, who may come from a variety of different professional backgrounds, in the concept of the lean enablers.

The main concern of this research is the adaptation of lean training for a virtual environment. Existing training methods have been analysed, along with the various ways in which they can be implemented, and these have been used in this research as a starting point from which to construct the virtual work environment. Through the research, a method has been developed to set up and run a training session using a virtual reality (VR) system by generating a structure to design the modelling elements that compose the virtual workplace, as well as establishing a method so that a trainee can navigate the simulated environment and perform tasks. A program to collect the performance measures and visualise the results has also been developed, with the aim of enabling the evaluation of a simulation run by assessors/trainers.

This research covers new ground in providing a simulated working environment, which can suit any trainee's professional background, to facilitate learning about the lean enablers. It offers the capacity of establishing a simulated work environment which can

represent the trainee’s workplace and provide the necessary practical experience in order to grasp the concept taught through the training program. Additionally it offers the capacity for assessors/trainers to observe the performance measures and the trainee’s behaviour, simultaneously, while undertaking a simulation run. These combinations of information can be complementary and enable assessors/trainers in providing the best feedback while improving the learning curve of a trainee.

Although training programmes in organisations have provided a number of improvements in completing work with high efficiency and minimum waste, the outcomes collected in this research demonstrate that their benefits can be pushed further in terms of providing a training method which can be accessible to a large variety of sectors.

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DEDICATION

Special dedication goes to:

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My dear sister Nilab Parwani, who always gives me the energy to go beyond my limits, and lastly

My younger brother Yama Kayumi, who has played a big part during my studies without him even realising.

Declaration

I declare that this research report is my own work and every effort has been made to indicate clearly the contributions from others by providing due reference to the literature, and acknowledgement. It has not been submitted before for any degree or examination in any other University. I further declare that I obtained the necessary authorisation and consent to carry out this research.

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Abbreviations and Glossary

VR	Virtual Reality
SOP	Standard Operating Procedure
SOR	Standard Operation Routine
SWES	Standard Work Element Sheet
SWCS	Standard Work Combination Sheet
SWC	Standard Work Chart
TWI	Training Within Industry
HMD	Head Mounted Displayer
CAD	Computer Aided Design
VDI	Virtual Disk Image
People	Health and Safety
Quality	Quality of production based on customer demand
Velocity	Process time
% blocking	The waiting time for the preceding machine which is waiting for the succeeding workstation to finish the jobs
% waiting	The time taken by the preceding workstation to complete the jobs so parts can be sent to the next workstation to be processed
% working	The percentage of time when machines are working

Chapter 1: Introduction

1.1 Overview

Today organisations are facing an increase in global competition, customers' requirements are becoming more demanding and work processes are becoming more and more elaborate. To overcome these challenges, Toyota developed a work concept known as "lean". The philosophy behind lean principles is "use less but achieve more" through restructuring workplaces and eliminating non value-added activities (Melton, 2005). Due to the pressure of improving work quality in order to stay competitive, many organisations have adopted the lean principles as opposed to the traditional mass production (Melton, 2005). Its implementation requires setting up a work environment where personnel have a deep understanding of the work to be done and can complete jobs in coordination with the lean principles. Training programmes are commonly used by many large organisations with the objective of providing staff members in a workplace with the required knowledge and skills to perform their job efficiently.

The aim of this research is to attempt the development of an innovative training program which can enable personnel to get a full grasp of the lean principles and to improve their skills.

1.2 Problem statement

To be part of the world market, organisations need to increase their productivity by investing in their work processes and skilled personnel as well as having the ability to adapt their work based on the customers' requirements (Terry, 2011). Ultimately they require staff members who have the capability of carrying out several different types of job. Training programmes can be a way to reach the required level of knowledge and of being able to meet customer demands. However, their use is not free of challenges, especially in aspects such as:

a) training a workforce on-the-job and facing the possible damages which can occur due to the lack of experience (Pennathur and Mital, 2003).
b) difficulty in measuring the effect of a training session on productivity at the individual level. Kenn et. al. (2013) have analysed the potential demand for "on-the-job-training" by conducting a survey within two Japanese automotive companies. The objective was to investigate the difference aspects of "on-the-job-training" and how much can it improve the productivity of an employee. The data collected through the survey describes an improvement in the relationship between productivity and organisational adjustments, however evaluating individual staff members was challenging,
c) providing a practical experience to trainees: this can be a predominant factor in conducting a successful training session. The necessity of having a working environment where a trainee can put the taught knowledge into practice is essential in providing an efficient session, however training programmes which use a simulated workplace are only able to provide one standard environment which cannot be adapted to guarantee suitability for all trainees. Hasan et. al. (2011) have focused their study on identifying the gap between the effectiveness of the learning environment and industry application on skills and competency in construction project success. Surveys were conducted with 420 respondents, which were composed of 50% employees and 50% employers. Using a correlation method, the results of the surveys demonstrated a gap between the

theoretical and the practical aspects of the work. Too much emphasis on specialisation was noticeable within organisations as well as a lack of cross fertilisation of ideas/experiences between departments – employees are encouraged to follow a unique specialisation as opposed to sharing knowledge between specialists of different areas. Additionally the practical aspect of training should not interfere with the ongoing work, however this requires providing an approach which can offer trainees the possibility of putting into practice the taught methods (Gadre et. al., 2011) and finally

d) enabling the "decision-making" aspects which are not always obvious in training programmes. Jenkins et. al. (2011) have looked at the decision-making aspect in a training programme for a synthetic environment through observing the way individuals make decisions and how closely it can be linked with their experience of the domain. The approach taken by the authors is to develop a prototypical model of decision-making to manipulate a tank; it consists of modelling the actual behaviour and extends this to a context independent prototypical model. The aim was to observe the relationship between the work to be performed and the decision-making strategy. Jenkins et. al. (2011) have highlighted the difficulty of information-based training such as lectures, handbooks or procedures to equip decision-makers with appropriate stored-procedures in order to cope with various situations.

1.3 The aims and objectives of research

This research has been part of the Technology Strategy Board (TSB – ref K1532G) focusing on "Accelerating process excellence using virtual discrete event process simulation"; it combines advanced visualisation capability with a lean training environment. Some of the objectives of the project were:

- to develop a lean training environment with the aim of improving both the skills of lean practitioners and the operation skills of those required to implement and operate the lean improvements. The training program will provide visual cues to lead new learners through individual lean process changes. Learners will be expected to use the simulated environment to analyse, to generate alternative solutions, to select the best solutions and to implement them.
- to establish an advanced visualisation capability, which is responsive to user needs and enables physical interaction with the simulated models, and understands the complexity of the trainees' behaviour. Moreover, a visualisation method is required to allow the learner to quickly assimilate the necessary information throughout the simulation.

Taking into consideration the aims of the Technology Strategy Board, this research investigates the possibility of the use of a virtual reality (VR) system as a support to set up a training session as well as enabling sets of tools which can help a trainee during the learning phase. The development of the training program is inspired by methods used within organisations to implement the lean principles and the several techniques used in video games for interaction in order to create a simulated environment where a trainee can be surrounded by the virtual workplace and be able to navigate and manipulate objects intuitively (Schubert and Strobach, 2012). The aspects treated in this research are the following:

a) exploring methods of training used within organisations and analysing the aspects of setting up and running a training session: examining the existing training methods, extracting the major elements relevant for the training program and adopting the best practices in the proposed method,
b) examining the implementation of the lean enablers in a workplace and how staff members of an organisation are trained: identifying the main aspects of *5S* and *Standard Operating Procedure (SOP),*
c) investigating the limitations of the equipment used in the virtual reality (VR) system and developing a method which will allow for interaction and make decisions possible during a training simulation, and
d) generating the performance measures of a simulation run and being able to analyse them.

The research will undertake each aspect based on lean thinking, and support will be provided by the Technology Strategy Board with the objective of establishing a virtual reality (VR) training program for lean principles.

1.4 Scope

The scope of the research includes:

- Developing a structure to implement a training environment which can enable the application of the 5S and Standard Operating Procedure (SOP),

- Having a flexible training environment – being able to customise the work environment or the work process,
- Developing a training environment with the purpose of conducting a simulation run for one learner at the time.

However, the cost aspect as well as energy consumption will not be part of the investigation.

1.5 Structure of the thesis

In chapter 1, a brief introduction is made regarding the challenges faced by organisations in order to improve work through providing the adequate training programme for their staff members. In addition, it describes the entire structure of the thesis and introduces the content of each chapter.

Chapter 2 reviews the lean concept in workplaces. It defines the lean principles and analyses methods of implementation. The chapter introduces the importance of lean, the relevant benefits and in particular, waste reduction and how can it be implemented in a non-lean environment. Additionally the literature reviews cover the lean enablers: what they represent and how can they be applicable in the context of this research.

Chapter 3 illustrates training programmes undertaken within organisations. This chapter looks at the variety of training methods developed in diverse sectors of activities and the concepts which have been implemented. Based on the literature review, the research identifies the organisations' common objectives and the approaches used to implement a training programme in workplaces. In the second part of the chapter, the virtual reality

(VR) system is examined: the characteristics of the system, how it has been used in a training context and how it benefits the research.

Chapter 4 describes the research methodology, which combines both quantitative and qualitative types. Based on the aims and objectives, the development steps of the *5S* training program are illustrated including the design of the modelling elements, the development of the "decision-making" tools and the generation the performance measures. Moreover the experiments are designed with the aim of investigating the advantages of having a training program using a virtual reality (VR) system by observing the effects of the "decision-making" tools on the outcome of a training session.

Chapter 5 illustrates the steps carried out to build the training program for *Standard Operating Procedure (SOP)*. Using the same foundation developed for the *5S* training program, the research goes further by enabling the use of the "*decision-making*" tools for the *SOP*, manipulating 3D modelling objects and visualising the performance measures in real time. As in chapter 4, a series of experiments will be conducted with the aim of demonstrating the benefits of the training program through evaluating the support of the "*decision-making*" tools provided for a trainee and how the program can improve learning.

Chapter 6 discusses the results obtained in this research. It begins with a review of the different training programmes illustrated in chapter 3, highlights the contribution of this research and illustrates the procedure to undertake in order to implement the proposed method in a training context. Additionally a discussion is carried out about the results collected during the simulation runs of the *5S* and *Standard Operating Procedure*

(SOP). Finally the limitations of the proposed method are mentioned: the causes of the limitations are described along with the solutions.

Chapter 7 draws conclusions from the research and summarises the contribution to existing knowledge.

Chapter 8 lays the ground for further research and investigation as it describes future work to extend the use of the lean manufacturing training program using a virtual reality (VR) system.

Chapter 2: Lean manufacturing and lean enablers

2.1 Introduction

This chapter describes the fundamental aspects of lean manufacturing, firstly through examining the elements that contribute towards the implementation of lean, then drawing an outline of the main principles and wastes in order to develop an environment that acts as a training improvement exercise.

2.2 Lean manufacturing

In the last century, manufacturing has experienced a huge expansion, especially in the automotive sector. Its revolution started at the beginning of 20^{th} century with a drastic increase in the demand for auto motives which led this sector to become more competitive. In 1910, after a period of careful observation, Henry Ford applied with a new manufacturing technique called *mass production* consisting of producing standardised products in large quantities (Alizon et. al., 2009). Many years later, in 1980, a second revolution took place within Toyota, known as the *Toyota Production System (TPS)* or "*lean manufacturing*" (Melton, 2005). Based on the main aspects already developed by Henry Ford in terms of *mass production*, lean manufacturing brought in a new way of thinking which focuses on customer values, reducing non-value added activities, operators' empowerment and involvement from the bottom up. It allows benefits such as the improvement of quality and safety with minimal errors, the customer demand, a stable working environment with clear standardised procedures which creates the foundations for constant improvement, and finally cost effectiveness with higher efficiency whilst using the same resources. Although having a reliable machine operating system is important, what is essential is the staff members' knowledge and how much understanding they have about the different activities that occur within the production line (Yousri et al, 2011).

Ohno and Shingo have underlined the importance of workers' involvement, especially in decision making, when it comes to process improvement (Granerud and Rocha, 2011) and (Anand et. al., 2009). In this research, adapting the learning of lean manufacturing principles for a virtual reality (VR) environment is taken into consideration by developing new ways of setting up a training session and analysing the results with the aim of rectifying errors, which can be caused by malpractices while working, and improving the current state of production.

2.3 Lean manufacturing principles

Lean manufacturing has been implemented in many industries and service sectors to maintain a competitive organisation and increase the global market – it stands on the five principles below (Khalil, 2005):

a) **Customer values** – concentrate on production based on customers' values whether they are internal or external. The processes are defined and analysed according to the customers' requirements and all the non-value added activities are targeted to be removed (Abdulmalek and Rajgopal, 2007).
b) **Value Stream** – represents a series of actions to bring products through the production lines, starting with raw material and ending with the customer. These actions consist of identifying the product or family of products as the target for improvement, drawing the current state map of how things are done and creating the future state mapping, representing the production after the

non-value added activities have been removed (Abdulmalek and Rajgopal, 2007).

c) **Flow process** – concentrates on arranging the work environment in order to provide a continuous flow where materials are available when needed as opposed to moving them in large batches (Melton, 2005),

d) **Pull system** – consists of setting up a production method where products are produced according to customers' requirements. The pace of the production is given by downstream activities requests – whenever a job is completed, materials are pulled from a downstream process. This process allows the reduction of inventory in the production lines (Ohno, 2011).

e) **Continuous improvement** – is based on keeping to the lean principles throughout the production and ensuring continuous improvement. It also focuses on eliminating wastes, reducing lead time, inventory and rework (Melton, 2005).

The objective of lean manufacturing is to obtain a high quality of product in order to meet customer requirements. It also ensures the minimisation/elimination of non-value added activities which are seen as wastes; they go against improvement by affecting the continuity of the production lines – lean wastes are discussed in section 2.4.

2.4 Lean wastes

To be able to implement the lean principles, it is essential to have an understanding of the wastes in manufacturing. Lean defines seven wastes which are:

a) **over-production:** it leads to the creation of a high level of inventory by producing too early or more than the required demand (Hicks, 2007),

b) **inventory:** is generated by ordering more raw materials than are required to fulfil the customer's order. Additional handling and space are also generated by the high level of inventory whether they are raw materials, work in progress or finished goods (Melton, 2005).

c) **transport:** occurs when unnecessary movement of materials is made. It can be defined in two aspects (Cuatrecasas-Arbos et. al., 2011):

    i) internal transportation which occurs with redundant movement of materials between the depot and the factory or within workstations due to poor layout: this can cause problems such as increasing the time taken to complete a product and causing a decrease in the product quality, and

    ii) external transportation related to unnecessary movement of raw material between suppliers and shop floor.

d) **over-processing:** happens when a process step does not add value to the product. It usually occurs for various reasons such as poor communication between suppliers and factory, process duplication, working with oversized batches, or other reasons which can cause production too early or the production of too much. Over-processing can lead to an increase in the level of inventory which can be the source of other problems (Abdulmalek and Rajgopal, 2007).

e) **waiting:** relates to queuing or the time taken to get hold of raw material, parts from the upstream process or send to downstream activities and tools. It causes operators, equipment or products to wait for materials to come or products to be sent to the downstream process. Waiting is considered to be an effect of different types of variability that can occur from the upstream or downstream process of a production line (Hicks, 2007).

f) **over-motion:** is linked with the extra steps taken by operators or equipment to complete a job/activity. Excessive motion can be caused by a poor layout, or an incorrect/ unclear job description (Melton, 2005).

g) **defects:** occurs when a product or service does not meet the specification or customer's expectations, which leads to either rework or scrap (Melton, 2005).

The wastes identified in lean are used in this research to develop the algorithms which will output the performance measures. They do not appear directly in the results; nevertheless through the performance of a trainee during a simulation run in the virtual working environment, wastes such as transportation, over processing, defects and waiting can occur. Therefore using them as parameters, they will enable the development of the algorithm that generates the outcomes of a training session.

2.5 Manufacturing system

The aim of the training program consists of providing a learning environment using the 3D models implemented in a virtual reality (VR) system where trainees can benefit by learning the lean principles and implementing them in a working environment.

Identifying the manufacturing system will allow the research to set up the training context and establish a learning method.

a) Types of manufacturing system

The purpose of lean training is to support organisations to overcome any gaps in knowledge that will cause the non-implementation of the lean principles (Yang et al, 2011). By exposing the different types of manufacturing system, identification of the appropriate system can be made for the purpose of developing the training program:

i) *job shop production* – a type of manufacturing process in which items are produced according to the customer's requirements. Production is planned to handle a wide range of products designed and performed at fixed plant locations using general purpose equipment (Khalil, 2005),

ii) *flexible manufacturing system* – contains flexibility in production which allows the manufacturing system to respond immediately in the case of predicted or unpredicted changes (Jahromi and Tavakkoli-Moghaddam, 2011),

iii) *assembly/disassembly system* – assembly manufacturing system is based on building together individual parts within the standard quality and customer demand. The reverse of it, disassembly, is defined as all of the processes that within a given time period dissociate the structure of geometrically defined parts (Pisuchpen, 2012), and

iv) *flow lines* – is composed of production lines where materials flow within the workstations and visit each work and storage area in fixed sequences. Flow lines are affected by the reliability of machines and buffer size.

Based on the method to transfer parts, Khalil (2005) has described three types of flow line:

a. asynchronous – related to transfer lines
b. synchronous – called production line and
c. continuous.

The type of manufacturing system applied in this research is *flow lines system.* It will allow the demonstration of the implementation of the training program in the virtual reality (VR) system, through:

i) enabling the research to look at aspects of lean in a working area and consequently develop a training program for learning purposes, and
ii) offering the possibility to implement a training material which can focus on the bigger picture – *the arrangement of a working environment* and to concentrate on an individual workstation – *the assembly process*.

2.6 Lean enablers

Lean enablers represent the application of lean principles, practices and tools related to aspects of the manufacturing management in order to enhance production (Suarez-Barraza, 2009). They are characterised as a list of practices which contain implicit knowledge on how to plan, implement and run a production using lean principles. They establish communications between managers and operators in order to set up a standardised procedure among the work team and maintain continuous improvement (Gilgeous and Gilgeous, 1999) and (Oppenheim et al, 2009). Bateman (2005) has illustrated aspects of lean enablers which cover production improvement and are used in this research to develop the features of the VR training programme in order to meet the following points:

a) *a common understanding of objectives* – involves setting up documentations and visual support for improvement, such as Standard Work Element Sheet (SWES)[1] for the *Standard Operating Procedure (SOP)*, and

b) *setting up structures that stop regressing* – consists of removing old methods that do not contribute to any improvement – relates to the aspect of standardisation which is one of the *5S* steps.

Saurin and Ferreira (2009) have focused their study on lean and assessed the impacts on the outcomes within workplaces. They have conducted frequent visits in industries and used checklists[2] to support their analysis in implementing lean. Additionally they enabled the research team to get acquainted with the activities of an organisation which promoted assessing the quality of lean production within workstations. However the approach taken by Saurin and Ferreira (2009) to analyse the implementation of lean involves the use of valuable time and can cause disruption in the production process. One of the alternatives ways of carrying out the analysis in production without causing disturbance in the work process is to have an environment which simulates the working environment with all its subtleties and generates the same types of results (Sadasivan and Gramopadhye, 2009). Therefore in this research, the approach taken can allow researchers (or assessors/trainers) to analyse a workplace through its simulated version, which consequently permits the assessors/trainers to try different alternatives in order to

[1] Used as a tool to set instructions and explain how to carry out the standard work.
[2] Used within a workplace to certify that all steps of the 5S have been implemented correctly

improve their observation and bring more elements to support the evaluation of implementing lean.

2.6.1 The lean tools and techniques

According to Deif (2012) lean tools can be used by staff members or managers of an organisation, or an external consultant in order to transform a mass producer working area into lean production and consequently to obtain a competitive performance.

Having just the lean tools and understanding the purpose of each one of them will not be enough to establish the principles and sustain them. Learning how to use the tools and putting them into a practical context is also an important part (Pennathur and Mital, 2003).

Bertholey et al (2009) have mentioned in their research how *5S* can improve organisation of the layout of workstations as well as enabling staff members to gain the adequate skills to make appropriate decisions. Likewise the *Standard Operating Procedure (SOP)* has been defined as a method to improve the work process and continuously encourage personnel to follow the standard procedure to produce parts (Mager et. al., 2007).

2.6.2 5S

a) Definition of 5S

Waldhausen et. al. (2010) have defined *5S* as a Japanese technique for restructuring the working environment. Originating within the Toyota production system (TPS), *5S* is considered beyond being just housekeeping within a workplace; it enables the improvement of a workplace by simplifying, organising and standardising the work process. Ultimately this method of structuring a workplace leads to wastes reduction and improves productivity as well as quality by keeping an organised working area and setting up visual components in order to achieve a consistent performance (Abdulmalek and Rajgopal, 2007), (Waldhausen et. al., 2009) and (Bayo-Moriones et. al.,2009).

In this research the *5S* is seen as a practice which allows the structuring of a working environment in order to achieve maximum productivity. Based on the five steps defined in table 2.1, the *5S* concept allows a team to set up a structured working environment by brainstorming where value added work is promoted – exposing a wide range of ideas, observing the non-value added process, reducing wastes and encouraging sustainable improvement, especially through “standardising” and “sustaining”.

b) The concept of 5S

According to Warwood and Knowles (2004) the aim is to offer sets of techniques allowing a standard approach to fulfil the required improvements. The concept was originated by Hirano (1996) who came up with the *5S* while working on production improvement among companies through implementing a system where production and inventory are controlled. The root of this concept is linked with the socio-historical and philosophical practices in Japan where often it is denoted by “do” and “techniques”. This vision is translated into the manufacturing sector by encompassing the aspects of analysing what is needed to fulfil the customer demand and maintaining a structured work amongst staff members as well as using the available “tools” appropriately in order to get maximum benefits (Gapp et al, 2008). The *5S* stands on five aspects aiming to maintain the daily work of an organisation by defining a routine in order to have an organised, smooth and efficient flow of activities (Bayo-Moriones et. al.,2010).

Bertholey et al (2009) have described the procedural steps of the *5S* as implemented in the Toyota Production System, mentioned in table 2.1.

Table 2.1: The principles of the 5S methodology (Bertholey et al, 2009) and (Bayo-Moriones et. al., 2009)

i)	*"Seiri"* – equivalent to sorting: the concept is based on distinguishing and sorting out necessary and unnecessary items, tools/materials and removing what is not used. Documentations and clear instructions are provided with the aim of guiding employees to identify each element of the working area, and organise them accordingly.
ii)	*"Seiton"* – related to simplifying: focuses on establishing suitable places for the necessary items with the objective of minimising time needed to access them.
iii)	*"Seiso"* – corresponding to cleaning: it consists of maintaining work environment, equipment and tools clean on a daily basis.
iv)	*"Sekisu"* – associated with standardisation: it is based on establishing documentation and regular evaluations in order to ensure that the working environment is following the *5S* concept and running at its optimum level.
v)	*"Shitsuke"* – mainly stated as sustain or self-discipline: the aim of the last step is to make *5S* methodology part of organisational culture and assuring employees are committed to long-term implementation of the plan which includes punctuality, safety and autonomous work in all levels of organisation.

c) Advantages of implementing 5S in a working environment

Within a large organisation, *5S* has allowed many advantages such as providing a solid internal structure integrating different departments with a working method which can contribute to the improvement of performance and create an agreeable working environment for employees, managers and suppliers (Ahmed et. al. ,2005). The advantages of implementing the *5S* concept have been noticed in aspects such as:

i) Safety – Bayo-Moriones et al (2009) conducted a study to investigate the application of the concept within organisations and assess its implementation. Statistical techniques have been used to test the association between 5S use, contextual factors and performance. The results demonstrated that in organisations where 5S were poorly implemented, the safety level was poor. Therefore a clean/structured workplace can considerably reduce the number of injuries sustained by workers; spilling any types of liquid/product whether chemical or otherwise can increase the chance of slips and falls, and eliminating transportation can minimise the risk of unnecessary exposure to hazards elsewhere.

ii) Reducing waste – the effect of organising/structuring a working area based on the *5S* principles reduces the amount of lost and damaged items. As the procedure requires standardising work, clear organisation and labelling, it allows employees to replace tools in a designated position after being used (Pillet and Maire, 2008).

iii) Work commitment – using *5S* to structure a working area means involving personnel in implementing the methods. As they are largely responsible for using equipment during a production, *5S* encourages participation in improving the work method by restructuring the workplace and ensuring it is maintained. Accordingly this involvement serves to engage each member of staff in long term sustainability and enhances their commitment as well as their pride in the work (Bertholey et. al., 2009). Waldhausen et. al. (2009) have investigated the application of lean and particularly the *5S* within surgery clinics where physicians, students, nurses, nurse practitioners and medical assistants were involved. The method consists of conducting an analysis of the effect of implementing the *5S* methodology over a six week periods. The *5S* technique was applied to standardise the exam rooms and office work space, and quantitative data was collected in order to observe the number of patients seen, the amount of time that patients were in the waiting rooms, and the involvement of staff members in taking part in the work method. The results demonstrated that the participants who undertook the *5S* concept in their daily work concluded that this mode of management and structuring work improved their work and identified new axes of improvement.

Moreover Ho (2010) has analysed the implementation of the *5S* within Japanese industries. The objective was to distinguish the advantages brought through the use of the *5S* by comparing the firms' production before and after its implementation. The case studies conducted by Ho (2010) analysed the performance of various businesses such as fast food restaurants, hospitals and automobile companies and the results described common benefits such as:

i) the framework offered by the *5S* develops and encourages a notion of awareness among workers in the work area, and
ii) increased self-confidence which can be beneficial for performance improvement at work.

In this research the notion of awareness is translated by having a working area where personnel can easily identify elements (parts, tools or workstations) and use them accordingly. Similarly Bhuiyan and Baghel (2005) state that maintaining improvement requires awareness of the various tools available to perform the job successfully and this awareness implies knowing the purpose of those tools, how it can help, where to access them and how to use them. Consequently this leads every staff member to work by having a clear understanding of the requirements as well as utilising the tools appropriately (Talaei-Khoei et. al., 2012). As for self-confidence, this research considers it as having the ability to make a decision based on the understanding of the working methods and analysing the situation in order to take appropriate actions for better results (Woodman et. al, 2010).

d) Use of the *5S* within organisations

The *5S* has been used for many years and the feedback received in response indicated that there was a lack of focus on measurement as well as dexterity in handling dynamic situations – not being able to assess accurately the state of a working area and making the necessary changes to improve the production (Ho, 2010). Therefore Massaki Imai (1997), who is the founder of the Kaizen Institute, has developed a checklist where each checkpoint is kept simple and concise, and quickly it became a standard. The use of the checklist is seen in this research as a way of evaluating whether each step of the *5S* has been correctly implemented. Additionally it allows assessors/trainers to evaluate the implementation of the concept during a simulation run and enable the provision of guidance to trainees.

Moreover the *5S* concept encourages teamwork during implementation. It requires a team to begin analysing the state of the workplace and to identify any opportunities for improvement. By conducting an analysis, the entire team can visualise potential improvements in their workplace and consequently begin implementing the *5S* (Moreira et al, 2008). Warwood and Knowles (2004) have conducted a series of surveys involving 100 companies based in UK, with the aim of investigating the impact of Japanese *5S* practice in UK industries. The outcome of the surveys described that 15 companies out of 100 have implemented the *5S* concept within their workplace and have experienced several benefits including an improvement in their staff involvement. Similarly Gapp et. al. (2008) have qualified the concept to be a high level management and organisational system that has a complex and philosophical meaning and explain that the objective of involving staff members in the implementation aspect is a strategy to ensure their commitment with regards to the new working structure and to maintain the long term benefits obtained. The case study undertaken by Gapp et. al. (2008) focused on collecting data from Japanese companies that use *5S* within their core management, and examines the managerial and organisational application of *5S* as well as the involvement of staff members in their daily tasks. The observation made by the authors emphasises an improvement the understanding between individuals, groups and organisations in terms of the output results as well as an enhanced relationship between customers and the organisation through:

i) placing strong emphasis on the requirements, and
ii) organising the workplace appropriately in order to produce the required products or services.

Another example of implementing the *5S* has been mentioned by Chowdary and George (2012) who used it to reduce wastes such as unnecessary inventory, and to improve production time. In order to accomplish this task, they have come up with an approach which helped the pharmaceutical manufacturing to restructure the layout. The method consists of observing the current performance of the workplace and identifies the source of problems (Chen et. al., 2010). It requires the analysis of the layout of the workplace and the way products are manufactured with the aim of identifying aspects that cause problems. Consequently, this gives a better picture to the managers of what is going on in the production area. Then the *5S* is used to improve the leanness of the organisation and to validate each stage of the implementation with the company's managers through redesigning the workstations in order to cover stages which generate wastes. In this research a trainee is challenged to work out the aspects of the workplace that need improvement and ultimately design a layout for more efficient working. Brainstorming is also encouraged between the trainer and trainee as part of guidance. It is used as a way for a trainer/assessor to introduce the *5S* training program and to challenge trainees' knowledge on this topic. With regards to analysis, it is done during the training session using the tools developed to observe the work environment.

Bertholey et. al. (2009) have studied the effects of the *5S* in an organisation. Using 60 managers from a research institute, analysis has been carried out in factories with the objective of evaluating the results of implementing *5S* in a working environment. Positive outcomes were collected, particularly in terms of identifying the difficulties faced before the implementation, by comparing the new work environment with the previous one. However in order to identify its benefits and advantages, the research team required several days of analysis and implementation before looking at the results and making the decision to take the *5S* on board to develop the working structure. This research focuses on allowing trainees to notice the benefits and observe results as the *5S* are being implemented. Eti et. al. (2006) have described an improvement in the learning curve when trainees are able to visualise the results and observe the benefits of applying the taught method. Providing an instant report of the outcome at the end of a training simulation, or as the simulation is going on, can enable trainees to visualise and understand the purpose of it and gain a better grasp of the concept.

Finally Gratiela (2012) have implemented the *5S* in a training program using a method called the “yellow tag strategy”. It is based on identifying environmental wastes (related to hazards and environment) in a working area, evaluating the needs and coming up with a solution. The tagging strategy, aiming to identify unused items, is kept in this research. It is used for analysing the workstations, highlighting items that are not used in production and removing them in order to have a simplified workplace with a clear work structure (Klepper et. al., 2005).

In this research the *5S* has been selected due to its use by many organisations to improve the working method and create an environment where personnel and managers have a common understanding of the requirements. Furthermore, based on its methodical approach for the organisation of a workplace (Bayo-Moriones et.al, 2009), it supplies a solid base for building a working area by involving staff members during the implementation of the *5S*. According to Bayo-Moriones et. al (2009) implementation requires commitment from every employee to take part in restructuring the workplace and enables (Bertholey et. al. 2009):

i) sorting out the workplace and clearly identifying the material flow,
ii) enabling the information and tools to be easily available, and
iii) having a standardised operation with visual components which allows the detection of anomalies in workstations.

Therefore the aim is to develop a training environment inspired by the methods implemented in industries and using the virtual reality (VR) system in order to have a training program with:

i) a simulated working environment where trainees can be fully engaged,
ii) flexibility of changing the simulated environment in order to provide different perspectives on how to implement the *5S*,
iii) visual components which can help trainees to explore working environment and analyse every aspect of it, and
iv) a system which provides real time results of a simulation run

Additionally from the description of the principles illustrated in table 2.1, aspects of analysis and "decision-making" are the key elements (Chauvin, Clostermann and Hoc, 2009), and the research also focuses on this in order to complete the VR training program.

2.6.3 Standard Operating Procedure (SOP)

a) Definition of SOP

The *Standard Operating Procedure (SOP)* in lean manufacturing is created by disciplined creation of requirements, analysing, documenting, disseminating and implementing the best practice where the work method offers a simplified and structured approach to ensure consistency and repeatability over time ((Bhuiyan and Baghel, 2005) and (Rivera and Chen, 2007).

In addition to the production process, Kennedy and Widener (2008) have defined the *SOP* as a way of leading the process based on customers' requirements, utilising the required materials, testing production and providing an efficient method to perform tasks. The *SOP* is critical for any improvement and key to success in lean manufacturing. The aim is to lead the production through (Imai, 1997):

i) representing the standard, simplest and quickest way to achieve the work,
ii) providing a base for training personnel,
iii) offering the best way to maintain the organisation's knowledge base,
iv) allowing measurement of performance, and
v) providing support for further improvement.

According to Simons and Zokaei (2005), *Standard Operating Procedure (SOP)* is a working method established for operators in production lines, which describes the nature of the tasks and where, when and by whom they are to be performed. Each step of the work process is clearly documented and circulated within workstations to encourage maintained improvement by reconsidering the work procedure if it is no longer efficient.

In this research *SOP* is defined as a practice which is focused on the work process by describing the recurring operations relevant for production. It supports the learning enhancement of the standard work in order to lead productions to a continuous improvement process through:

i) standardising the work process and describing activities, and
ii) illustrating tasks through documentation and visual aids *(describing a series of predefined processes)* in order to allow staff members to proficiently complete the jobs.

b) Concept of Standard Operating Procedure (SOP)

The concept of *SOP* stands on a series of steps to assemble an item. Each of those steps has been designed in order to provide a simple way for an operator to perform a job easily and efficiently. The *SOP* allows the performance of tasks sequentially through combining the usage of all resources effectively such as tools and raw materials (Aguado et. al., 2012). Similarly Schmid (2012) has used the *SOP* in a laboratory to establish a consistent work manner which involves high risk activity such as sorting out unfixed cells. The method consisted of conducting a risk assessment on the hazards associated with the handling and processing of samples in a laboratory and, with the supervision of safety professionals, determining the appropriate biosafety level that can be expected to be effective in preventing laboratory-acquired infections. Then the *SOP* was written describing a set of instructions that document a routine/repetitive activity to be followed – it provides personnel with information on how to perform a task properly and ensures consistency of the work of different individuals as well as playing an important part in the laboratory's safety. As a result the author concluded that Standard Operating Procedure (*SOP*) provides guidance by deconstructing any process into clear and coherent tasks with the aim of providing consistency in production and increasing performance.

Setting up a *SOP* in a working area relies on analysing, collecting data and identifying the wastes in the current practice used by operators. Then a redesigning of the processes is required in order to provide another procedure to perform the job where wastes are reduced or eliminated and the production performance is increased (Lin and Yen, 2011). Kock (2007) describes the *SOP* as a concept which consists of:

i) processing at the rate where products meet the customer demand,

ii) performing tasks using a precise work sequence in order to maximise quality and minimise wastes, and

iii) keeping the process operating smoothly through reducing the inventory, including parts in machines.

c) Importance of SOP in lean

The implementation of the *Standard Operating Procedure (SOP)* has offered several benefits such as preventing problems when being in a workplace and strengthening the work quality (Cudney and Fargher, 2000). Many advantages of the *SOP* have been mentioned by several authors including:

i) having a consistent work manner which generally generates better results instead of letting personnel figure out the work tasks (Loven and Helender, 1997),

ii) allowing a reduction of the variation in workstations, which consequently increases productivity (Simatupang et al, 2012) and (Grounds et al, 2008),

iii) providing instructions which describe the work method step by step and can facilitate training. The documentation can also be used by assessors/trainers as a reference to design a training program and to ensure that during the training all elements of the *SOP* have been completed (Cha et. al., 2012),

iv) enabling staff members to self-support each other regarding each specific task using the *SOP* documentation as guidance. This method of working encourages cooperative teamwork on a daily basis, which can reduce poor quality production (Peplies et. al. , 2008), and

v) developing and following a *Standard Operating Procedure (SOP)* in a hazardous[3] working environment may help reduce risks of accidents and provide legal protection if an environmental accident occurs (Schmid, 2012).

The entire method stands on documentation which provides a baseline of when a change of process occurs or new personnel have been transferred to a workplace and training is necessary (Bachmann, 2009). It uses visual support such as a Standard Work Elementary Sheet (SWES), to describe the tasks to perform sequentially including the steps to undertake, the appropriate tool to use, manipulating parts and operating a workstation (Lin and Yen, 2011) and (Grounds et al, 2008). In this research the Standard Work Element Sheet (SWES) is used to support communication of the work procedure to a trainee before a simulation run is carried out. The objective is to prepare a trainee by introducing the virtual reality (VR) system and to give the instructions for a training session.

Finally Kennedy and Widener (2008) have investigated the design of a control structure for lean manufacturing and developed a framework that advances theory. They have conducted a series of analyses within 265 industries by measuring production performance with and without the implementation of the *SOP* and observing the benefits of *Standard Operating Procedure (SOP)*. The analyses demonstrate that *Standard Operating Procedure (SOP)* enables a strong behavioural control to align employees' efforts with the organisation's objectives, consistency in production and maintaining low inventories. Kennedy and Widener (2008) affirmed that it provides a solid support when it comes to ensuring a steady flow of consistent products – a high

[3] It defines the health and safety while performing work, this aspect has been treated further in section 5.2.

level of standardisation is positively associated with high quality. They also underline the importance of employee empowerment, visualisation in the work area and training. Additionally their observations demonstrated that the implementation of the *SOP* within workplace offers the possibility for staff members to perform work with a good pace and with improved performance in terms of quality of production as opposed to having a production lines where standard work is non-existent with a fast pace and exhibiting the waste of “over production”.

d) Use of the Standard Operating Procedure (SOP) within lean manufacturing

Aguado et. al (2012) have developed a methodology of implementing the *SOP* and keeping the lean principles as the main source. Their approach consists of identifying two aspects which are:

i) *sustainable production* – a disciplinary working method where operators follow the *SOP* instructions, and
ii) *efficient production* – wastes reduction.

These have been put together with the aim of creating a synergy in order to meet customer demand and offer a working atmosphere where improvement can be made. Aguado et .al’s (2012) method, which is composed of long term vision, efficiency and sustainability, looks at balancing competitiveness of business and economic development. Through analysing the work area, each aspect linked with sustainable improvement is quantified and then ultimately a design of the standardized work is derived which leads to an efficient and sustainable workplace. Similarly in this research, a focus is made in order to enable the setting up of a standardised procedure where trainees can implement the working method defined in the Standard Work Element

Sheet (SWES) as well as reducing wastes while performing tasks in the training simulation. In addition, taking into account that *SOP* can be evolved, the research requires developing a simulated working environment where the standard procedure can be easily changed depending on the type of operation to be performed.

SOP is also used for the purpose of reducing/eliminating hazards associated with handling and processing work. Schmid (2012) has analysed this aspect and came out with a method which consists of:

i) determining a work process which will combine practices and safety equipment, and
ii) reviewing the efficiency of the work process and the facility safeguards used to determine the *SOP*.

The safety issue is an aspect taken into account in lean, and part of the advantages offered by the *SOP* is to provide guidelines which include the safety aspect at work (Mager et. al., 2007). It is crucial to include safety while defining the *SOP* as well as ensuring that the facility safeguards are not overlooked during the simulation process. Therefore the training program needs to include health and safety by reflecting in the results how those facilities have been used – highlighting the importance of these aspects as being part of the SOP and making the trainee aware that their use is essential.

Besides, Mager et al (2007) have stated the importance of this practice through setting up a standard identifier on the entire entities present in a workplace as well as each step of the standard work process in order to obtain a simplified work assembly and an improvement in quality. According to Faggion and Tu (2007) simplifying and documenting the work process helps members of staff and managers to improve communication and understand the instructions. However Mager et al's (2007) research has not mentioned a case when a standard work would require flexibility, in other words necessitating changes in the work procedure as products alter, nor has it mentioned how the current designed *SOP* improves future production. Therefore having flexibility in defining the work procedure can help tremendously by having a training program where the work process can be altered based on the product to manufacture. It can provide different approaches for the same concept and inevitably capture the interest of trainees coming from a variety of different backgrounds (Jensen and Friche, 2007).

Finally Faggion and Tu (2007) have focused their research using the *SOP* in the context of developing guidelines for a dental practice. They laid out the *Standard Operating Procedure (SOP)* documentation in a flowchart in order to provide better guidance for following the work procedure as well as putting forward the idea of allowing workers involvement in "decision-making". Having guidelines on how to perform a job as well as the flexibility of analysing a situation allows development of the "decision-making" aspect which can lead to improved skills as well as increased confidence at work (Jenkins et. al., 2010). Therefore in this research using the *SOP* to guide the trainee and allowing the flexibility of making decisions can be a good approach in providing a session with the aim of improving the understanding of lean.

In this research the *Standard Operating Procedure (SOP)* has been selected due to its benefits and its method of implementation. Two elementary factors have been discerned. First it can provide good resources with regards to the assessment of a training session. Using the procedure started for the *5S*, the research can utilise what has been built in order to make the evaluation of the a training session more effective by providing results on how the *SOP* has been performed as well as offering a detailed report on each step of the assembly procedure – developing a method to analyse a trainee's actions during a simulation run and generating the performance measures accordingly. Secondly it can help the research in developing an environment where the focus can be on the performance of tasks within the virtual reality (VR) training program – analysing a working environment, enabling tools which will support the manipulation of parts and evolve the "*decision-making*" skills. *SOP* training would permit trainees to gain a tremendous understanding of the benefits of lean through following the standard procedure such as the Standard Work Element Sheet (SWES) described in appendix 2.2.

Chapter 3: Lean training and Virtual Reality (VR) system

3.1 Introduction

This chapter examines the traditional methods used among organisations to set up training for a specific topic by carrying out a literature review. The second part of the chapter looks at the virtual reality (VR) system, illustrating its features and analysing the potential of the system for use as a training program/training simulation.

3.2 Definition of Lean training

Lean training originates from the *Toyota Production System (TPS)* with the aim of providing the best strategy for manufacturing practice and effectiveness against competition (Shah and Ward, 2003). It has been implemented by the majority of large organisations in order to provide their employees with the possibility of gaining all the required knowledge to work efficiently and increase productivity (Herron and Hicks, 2008). Similarly Patnaik et al (2011) state that lean training is *"the systematic development of the knowledge, skills and attitudes required by an individual to perform adequately a given task or job".* It helps staff members to develop skills to become productive in a working environment and process tasks in order to meet customer demand (Tavil, 2010).

Additionally Schwarstzman et al (2011) have described lean training to be a learning method which brings a modern perspective on individual development and enhances personnel skills at different levels, for example enabling them to gain a standard ability to perform a specific task as well as supporting the learning process to help them overcome any gap in knowledge and skills.

The concept of lean training is intended as an interactive learning process which simulates a practical environment – giving the opportunity to put into practice the required abilities by encouraging pupils' learning through different perspectives such as trainers' thinking, trainee views and the interaction between trainee and trainer (Morge et al, 2010) and (Matyusz, 2011). Herron and Hicks (2008) have also mentioned the communication aspect in lean training, the objective of structuring a workplace and focusing on providing the essential skills and knowledge for personnel in order to make significant improvements in production quality and delivery, as well as encouraging the development of partnership between customers and suppliers. Likewise, Doolen and Hacker (2005) have added other elements of lean training which are:

a) a clear understanding of the lean principles and how to implement the concept at work,
b) a training method which makes the learning of the concepts an enjoyable task instead of hard work and
c) clear instructions which improve understanding and aid the mastery of the essence of the taught methods.

Finally Thiry (2004) has described lean training as a way to offer the possibility of separating the different aspects of the lean principles in order to make the training sessions efficient as well as providing a practical approach in order to deliver clear, instructed session and concrete meaning of the principles. As a result, the taught skills can lead to the development of the abilities of a staff member whilst satisfying customer demands (Karaman et. al., 2012) and (Sadasivan and Gramopadhye, 2009).

3.3 The benefits of applying lean training

According to Wickramasinghe and Wickramasinghe (2011) and Liebisch and Gruhs (2012) trained personnel can make a tremendous difference in meeting the standard quality especially in corporations when a large number of employees with diverse skills are involved. Deros et. al. (2012) have evaluated the effectiveness of training in "advanced quality management" practices by comparing participants' level of quality knowledge, understanding and practices before and after attending the training programs. The aim was to evaluate participants' perceptions with respect to the overall training program, teaching materials and delivery methods. Therefore a workshop/ training course was established by the authors along with a survey, which included a section on the purpose of the training course and questions related to the taught concepts such as *5S* and *Standard Operating Procedure (SOP)*. The results demonstrated a significant improvement with respects to participants' level of understanding after they had attended *5S* and *Standard Operating Procedure (SOP)* training courses. Finally Deros et. al (2012) added that employers strongly believed in providing staff with appropriate training for improving their product quality and productivity in order to enhance their company's competitive advantage'. Similarly Perez and Sanchez (2000) and Rezaei et al (2009) have conducted a series of surveys within 28 automotive companies in the region of Aragon in Spain with the aim of analysing the technology management, the flexibility in practices and the relationship with other companies such as suppliers and customers. The observation made during the surveys describes that among the targeted industries more than 80% of companies undertake regular training in order to keep their staff members' knowledge up to date as well as for them to maintain a high performance at work.

Lean training can be a way of spreading the lean principles within a large organisation and ensuring that all personnel across different departments use the same work ethic and are heading towards common goals (Salleh et. al., 2012).

In addition, Kennedy and Widener (2008) have quoted that *"firms empower employees by providing them with information that enables them to participate in decision-making that affects organizational outcome".* Specific training for each job activity is designed using a "structured development map" which can offer a simulated environment where the lean principles are taught through practice (Pollitt, 2010). Consequently the outcomes offer considerable advantages such as being able to adapt the work according to the production. In the study conducted by Ariga et. al. (2013) on the organisation adjustment and training programme, an analysis has been done by carrying out a survey among assemblers and foremen in representative Japanese automobile makers. The aim of the study is to evaluate the method and demonstrate its contribution to improved productivity. After gathering all the data, the outcomes reveal that among staff that followed the training, all came out with higher skills and competence in their role and the difference in work quality was noticeable. In this research, the approach taken consists of simulating a specific work environment where the practice of lean principles can be performed, allowing the trainees immersion in a simulated working environment matching their background.

Another advantage has been noticed by Treville and Antonakis (2006) related to motivation at work. Before lean was used as a work method among organisations, motivation was traditionally without context and considered as a secondary element which would come about as the work progressed. However, part of the lean training's aims is to motivate personnel who are directly related to production. The working method designed based on the lean principles includes motivation within work and one of the objectives of training is to motivate the trainees. The lean principles and motivation at work are two important aspects required to be treated equally in a training programme (Hsu and Chen, 2011). Therefore in this research, the training program can also be seen as a way of providing a training simulation where trainees can express motivation, interests in participating and initiate suggestions either by making decisions during simulation or expressing ideas during brainstorming. Gegenfurtner and Vauras (2012) have explained the impact of making decisions on motivation. The staff member feels more valued knowing that suggestions are taken into consideration. In addition, Hedlund et. al (2010) have illustrated two types of motivation: "intrinsic" and "extrinsic". "Intrinsic" motivation is defined when tasks are performed purely because they are interesting or enjoyable for the trainee, whereas "extrinsic" motivation relates to tasks performed for "instrumental" reasons for example being driven by the reward of improving the performance measures. However the motivation aspect is not part of the performance results collected in sections 4.3 and 5.2.

3.4 Traditional training methods

The lean principles have proven their efficiency over time in enhancing work among organisations as mentioned in section 2.2. The skills and knowledge in lean are a resourceful way to design a working area for the purpose of obtaining an improvement in work quality and for minimising wastes. The relationship between employee qualifications and competitiveness has been studied by Chryssolouris et. al. (2013), where an approach (called by the authors the knowledge triangle in manufacturing) has been introduced to build skills and competences in manufacturing. This approach is based on a model called "Teaching Factory", which assimilates a factory environment in a classroom. The aim is to integrate the cornerstones of the knowledge triangle, which are research, education and innovation, in support of the manufacturing education in order to obtain a new paradigm of both academic and industrial learning. The “teaching Factory” concept can allow engineering activities and hands-on practice under industrial conditions for university students as well as the taking-up of research results and industrial learning activities for engineers. In order to validate this concept, the authors took part in a project which involved several organisations such as Festo and Volvo in order to support the implementation and validation of the “Teaching factory” approach. This approach has been defined in two ways: industrial practices to the classroom and knowledge to the factory. Based on the outputs of the project, the “Teaching Factory” approach can contribute to improving engineering skills. The technological innovation and knowledge delivery mechanisms in real life practice can promote the exciting quality of manufacturing and enable trainees to address real life problems under business conditions. The use of scientific approaches and cutting edge technologies can be a support to the concurrent development of technologies and skills to improve product / process innovation and help knowledge-based manufacturing.

The aims of a training programme are an important element in the design, implementation and evaluation of a session (Sadasivan and Gramopadhye, 2009) – allowing the setting up of a suitable simulation environment to teach the appropriate knowledge and practices which will help personnel to perform tasks successfully (Hogan, 2003) and (Mirehei, 2011). The training program also provides sufficient resources in terms of pedagogic materials and practices to support the learning process for staff members who are performing a specific job and assists bridging the performance gap as well as enabling the fulfilment of the assigned jobs proficiently (Rebsamen et al, 2010).

Adapting the lean enablers into a VR training program requires features which will enable its application in several sectors. The general structure of training programmes mentioned in table 3.1 can help this research to have a foundation in investigating and developing features which can be implemented within the VR training program. The illustrated steps represent the setting up of a training session according to the needs of an organisation. It shows all the main aspects which are taken into account in order to establish the appropriate session – the required types of skills and knowledge.

Table 3.1: General features of training programmes within organisations (Rebsamen et al, 2010) and (Mirehei, 2011)

a) **Analysing training needs:** setting up the learning purpose through:
   i) analysing the knowledge, skills and behaviour required for each job, and
   ii) assessing the level of competency of staff members.

b) **Setting up the aims and the learning objectives:** specifying trainees' tasks which will be the subject of the training.

c) **Designing training strategy:** determining the training needs, e.g. designing courses, the key learning points that trainees must grasp via the provided learning material.

d) **Implementing training strategies:** putting the training program into practice.

e) **Validation:** assessing the quality and effectiveness of the training programme.

The objective of this section is to investigate existing training programmes used within organisations and to identify the common elements. This investigation can help this research to get a better grasp of the used methods, through studying their application and the outputs collected, and encompassing all the information collected from the literature review in order to develop the training program.

3.4.1 Structure of a training programme

Nowadays various training methods exist, in the field of lean principles, which look at developing a learning environment and making the understanding of lean practice easier and faster through:

a) setting up a simulated environment which represents a workplace with all its complexity (Boyle et al, 2011),
b) giving a visual explanation of the methods chosen to be taught to a trainee (Lee-Mortimer, 2008), and
c) observing the performance measures during the training simulation (Boyle et al, 2011).

According to Maldonado et. al. (2005) these aspects are particularly important as conventional wisdom indicates that "*firms are willing to pay only what is required in terms of teaching specific skills*". Therefore general criteria described in table 3.2 have been settled by organisations to ensure all the required elements of a concept are taught to trainees.

Table 3.2: Traditional features required in a training programme

Criteria	Description	*References*
Decision-making	Providing enough material to help the understanding of the methodology and consequently enabling the gaining of sufficient experience and knowledge to improve decision-making.	*(Jenkins et. al., 2010), (Chauvin et. al., 2009)*
Educational components	Based on providing the trainees with the academic understanding of the rules and principles. Several platforms can be used for example a web based interactive teaching tutorial.	*(Kobak et. al., 2003)*
Applied components	Involves an interface which allows assessors/trainers to observe, evaluate and provide feedback to the trainee. Several observation methods can be used such as live remote videoconferencing.	*(Kobak et. al., 2003)*
Data analysis	Being able to receive elementary data (such as performance measures) to evaluate the knowledge gained by the trainee.	*(Rowen et. al., 2011)*
Accessible training platform	In most situations, the web based training programme (also called an e-learning programme) is used due to its vast dissemination areas. Trainees can benefit from all the training material without travelling a long distance.	*(Jang et. al., 2012)*
Visual components	Visual components allow trainees and assessors to get information about the work environment. They provide visual support to the trainee to identify the needs/problems in order to come up with a solution as well as supporting the assessor by constructing performance feedback.	*(Kennedy and Widener, 2008)*

Thiry (2003) has described two types of training model which are:

a) "*The Taylor Driscoll and Binning integrative training needs analysis model" –* the model is based on *performance analysis* – It looks at different variables (such as the layout of the workstations, hazardous items in the working area or the assembly process performed by operators) that can affect the success or the failure of a specific training programme in terms of its expected results, and

b) "*the Baldwin and Ford learning transfer model" –* a training model that focuses on "*the training-input factors"* that affect the training outcomes. Those input factors could be symbolised by the trainee's characteristics (trainee's abilities, personality or motivation), training design (principles of learning, sequencing, training content), or working environment (support given, opportunity to use).

In this research a combination of both models have been implemented in order to value the importance of having a workplace where production can be done according to the safety measurements (aim of the *5S* training program) and a working procedure can be set up in order to improve performance (through the *Standard Operating Procedure (SOP)*). Consequently the aim is to provide a training program that offers sufficient elements for performance improvement in a training session as well as permit the trainee to be challenged in several areas including knowledge and practical skills.

Table 3.2 describes the common plan followed by organisations to run a training session and guarantee each aspect has been fulfilled. The plan enables the support of the trainees' learning process and ensures that the theoretical and the practical aspects have been undertaken and understood (Raybourn, 2007).

3.4.2 Example of existing training programme used within diverse sectors of activities

According to Nieto-Montenegro et. al. (2008) a training programme needs to be based on appropriate education such as allowing "learning materials" and "practical training", which incorporates activities that support skills development relevant to real life situations in which the workers can put information into practice. For example in the domain of agriculture, a training session can raise the awareness of the possibility that E. coli bacteria may accumulate under fingernails and consequently should demonstrate the correct hand washing procedure in order to allow the learner to practice until the procedure is understood and applied successfully.

a) Training Within Industry

"*Training Within Industry (TWI)*" is a concept used among industries and was developed in the USA after the Second World War with the objective of training managers and team leaders to direct unskilled operators faster and more effectively in order to perform the required work. The "*Training Within Industry (TWI)*" methodology stands on four principles, which are (Wagner, 2009):

i) standards must be set up,
ii) good instruction must be established,
iii) continued training must be maintained, and
iv) training must not end too soon.

The aim is to make those principles become an integral part of the industry's process and emphasise the importance of selecting the appropriate staff member to be trained and how trainers should instruct as well as organise, develop and deploy a session (Graup and Wrona, 2006). According to Ker et. al. (2003) trainers play an important part in the quality of a training session which can lead to different outcomes based on their profiles and their pedagogic level. Taking this into account, this research looks at developing a training environment where the quality and the performance of a training session do not need to depend on the trainers'/assessors' skills, in other words a simulation run does not require that the assessors/trainers guide the trainee in performing the tasks. In a large organisation, this can guarantee delivering the same training quality to all trainees and ensure they all get the required materials to understand the lean enablers and then implement them in their work.

b) Establishing/designing a training session

Neal (2013) has used several techniques in order to deliver training methods for new employees in food production; the method consists of carrying out training sessions by following one of the approaches, which are:

i) written instructions of the job to perform,
ii) physical demonstration of the tasks to complete,
iii) written instruction and physical demonstration or
iv) a complete lack of any instruction or demonstration.

The aim was to analyse the current methods used in a production plant and identify which of the proposed approaches can suit the purpose of the training. The experiments were carried out with the participation of recent graduates and the objective was to slice four slices of bologna, which is a type of pasta, following a particular thickness using the appropriate equipment and then cleaning them to the right standard for the next use. The participants were divided into four groups and each one of them was assigned to a pre-designed experiment mentioned above. The results of the experiments carried out by Neal (2013) show the participant who did not receive instructions or demonstration managed to complete the job faster than the others, however the observations made on the completed tasks show results of better work quality for those who received written instructions and practical demonstrations of the tasks to perform. Similarly to the experiments described by Neal (2013), especially on having a training programme which has "written instruction and demonstration", this research focuses on designing a simulated work environment where trainees would have the opportunity to gain practical experience of the work to be completed. The instructions remain an important part as they provide the necessary information for the trainee to understand the requirements and perform the job. However the demonstration may not suit the purpose of this research as it may discourage a trainee from analysing the work situation. One of the important aspects of training within a virtual reality (VR) system is to offer to the trainee some flexibility of making decisions as opposed to instructing the completion of a job in a particular way (Brunner et. al., 2004).

In a separate study, Boyle et. al. **(**2011) examined training sessions for managers in helping manufacturing organisations to achieve lean objectives. The proposed model aims to highlight the relationship between various key drivers of lean such as external information which could come from training programmes. Boyle et. al. (2011) have looked at the various outcomes that managers turn to in order to seek guidance on how to implement lean efficiently. The model established by the authors is constructed based on literature reviews and interviews with operations managers of 109 companies from various sectors. Out of the total number of companies, 47 percent of the companies that replied to the interview mentioned providing staff members with the necessary knowledge and practice in order to make use of lean in a workplace and ultimately increasing the speed of implementation. Improving the time that will take to implement lean is an important aspect which makes it essential for an organisation to have a training programme where the knowledge gained is used as quickly as possible in order to keep up with the competition (Macpherson and Jayawarna, 2007). The second aspect mentioned by Boyle et. al. (2011) is standardisation – the objective is to ensure the work structure could be used throughout the work processes and therefore even for an international company a unique work standard can be established Pollitt (2006). On the subject of speed of implementation, in this research the focus was to have a training program where the trainee could understand the advantage of the lean enablers and their purposes. Pollitt (2006) has mentioned that being able to observe the effect of a principle makes for easier understanding. Therefore with the same vision, having a program where its features can allow the observation of the effect of the performance measures, and understand the benefits of implementing the lean enablers, can make the training session proficient. The other aspect mentioned which relates to standardisation has been taken into account in this research through the *5S* training program and also *Standard Operating Procedure (SOP)* which ensures that the training program will reflect the standard procedure establish in the Standard Work Element Sheet (SWES).

Finally, establishing a workplace can serve the practical aspect of training, nevertheless it can become costly to develop and cannot be easily moved to another location (Dessouky et. al., 2001), (Mujber et. al., 2004) and (Goulding et. al., 2011). Therefore a VR training program would be an effective way for a staff member to achieve the desired practical experience in order to grasp the required knowledge to apply the lean enablers at work. As mentioned by Wang et. al. (2009), a virtual reality (VR) system has many advantages over a real life training environment, such as the flexibility of exploring different ways of completing a job as well as less time-consumption to design models and analyse work processes in a simulation. It also enables the simulation of a working environment and having all the elements (such as parts, tools and workstations) which represent the trainee's workplace and the carrying out of exercises during simulation runs. The concept behind designing a VR training program stands on three aspects which are (Goulding et. al., 2011):

i) allowing assessors to set up the training within the VR system by establishing the working environment such as the environments defined in sections 4.3 and 5.2, and the requirements of the session.
ii) enabling a workplace where trainees can perform the exercise according to the instructions and aim to meet the requirements – based on analysing, acting and receiving feedback, and
iii) providing an output at the end of a session where the trainee can analyse the results of the performance.

c) "On the job training": delivering training while working

"On the job training" has been presented by Laird et. al. (2003) as a method to maintain personnel's skills and knowledge while being at work; it is used as a tool to train newcomers efficiently, using experienced employees and has been proven to develop skills and knowledge while working. Nevertheless the downside has been illustrated by Clark and Wall (1998) who documented the disadvantages. Production efficiency is affected, as well as quality, due to the fact that even if newcomers are supervised by seniors this cannot prevent mistakes during production and can cause major damage. In addition, lack of experience/learning phases can limit the performance of production lines.

3.5 Virtual reality (VR) system

The first concept of virtual reality (VR) was presented in 1965 by Ivan Sutherland where he introduced his idea of having a virtual world in a "window" that looks and sounds real, and responds to the users realistically based on the actions performed. He managed to build the first prototype of a head mounted displayer with an appropriate head tracking system. It consisted of displaying a virtual environment to the users in stereo view which was updated correctly according to the position and orientation of the user's head (Cheng et. al., 2009) and (Lu et. al., 1999). In the early 1990s, NASA investigated further into the VR system, especially the hardware aspect, by elaborating a sophisticated motion capture system to track the body as well as further developing the head mounted displayer (HMD) (Hale, 1995).

3.5.1 Definition of virtual reality system

A virtual environment known as *Virtual Reality* (VR) or *Virtual Interface* has attracted many researchers in field of simulation. According to Mahdjoub et. al. (2010), a virtual interface is a multimodal interaction with an interface and a responsive computer to generate a virtual environment. The main focus is on interaction, which combines an adequate presentation of the environment with its manipulation.

Additionally Choi et. al. (2002) have classified the VR system as multiple modelled parts where the overall process is simulated realistically by imitating the physical assembly processes. Dynamic behaviours of 3D objects in the virtual environment are implemented using physical laws.

In this research a VR system has been defined as a system which gives the illusion of being in the 3D environment through a stereoscopic head-mounted device (HMD).

Combining the use of a head tracker and the body motion capture, the user can interact with the workspace virtually and navigate the environment and manipulate objects as he/she would do in the real world through the motion capture equipment. Additionally the VR system can be seen as an evolution of the man-machine interface from the computer screen, keyboard, and mouse to the system of HMD and hand input device (usually a joystick or a glove) and ultimately it can simulate any working environment by recreating each element virtually as well as offering the possibility of developing extra features to enhance the usage.

3.5.2 Characteristics of virtual reality system

The development of the VR system is reaching a level where it is becoming more significant in all types of architecture and design. Trika et. al. (1997) have presented *Computer Aided Design* (CAD) to be an important design format since the mid-1970s; it has allowed users to draw three-dimensional images on a computer in order to integrate them into a virtual reality (VR) system to build the desired working environment. In this research a similar approach has been undertaken to design the modelling environment in small parts and group them in order to obtain the virtual environment. This approach provides effective support for designing complex models which can be rendered easily into the VR system (Gaoliang et. al., 2008).

Moreover, according to Si and Yang (2012) VR system integrates the latest achievements of computer graphics such as computer simulation, advanced sensors, a high definition displayer and network parallel processing equipment, which can ultimately allow the system to be flexible in the following aspects:

a) *Implementation:*

i) *Graphic rendering*: rendering in order to obtain a visual representation of the modelled object including the surface textures

ii) *Physical modelling*: representing different tissue charactering the 3D object and enabling their dynamic changes (the physical interaction in the virtual world)

iii) *Collision detection*: computational detection and reaction to the intersection of two virtual volumes.

b) *Visualisation:*

i) Adopting a range of different camera views which can go out of the body, over the shoulder and bird's-eye view, and allowing the ability of zooming in and out with a virtual camera.

ii) *Graphic display*: Holographic or 3D devices for display of visual information

c) *Manipulation:*

i) *Motion capture equipment*: navigating and manipulating objects in the same way as done in the real world. Using equipment which can capture body motion and translate it into the VR system which can enable head and hand movement for observing and moving objects.

ii) *Haptic interaction*: articulating arms or tactile sensors for tactile interaction with virtual environment

d) *Communication:*

i) speaking, triggering simple graphical gestures, and exchanging text messages,

ii) posting text messages on simple message-board objects located within the virtual world.

The virtual reality (VR) system can be involved in several trainings, allowing different levels of implementation according to the nature of the training program (whether it is a training session related to *5S* or *Standard Operating Procedure (SOP)*) due to its flexibility. It can be run on a stereoscopic displayer with a "haptic device"[4] or on a simple desktop computer driven by a mouse (Han et. al., 2008); it all depends on the intended actions to be carried out. Independently of the chosen environment, which will determine the level of user immersion in the system, the interaction and simulation of the model is a powerful tool from early design stages to final customer training systems (Mujber et. al., 2004).

3.5.3 Strength of the virtual reality (VR) system

The nature of the virtual reality (VR) system means it incorporates many advantages for all users regardless of the body type such as size or height, or disabilities. It offers an equal opportunity for everybody to have the same degree of freedom in movement (Blach et. al., 1998). Similarly to the advantages mentioned by Mujber et. al. (2004), Liu and Zhang (2010), Liu and Zhang (2008) and Xu and Taylor (2002) pushed the investigation further in identifying the benefits of using a VR system in designing a training environment. A list of benefits has been drawn by the authors after analysing and using the system. It includes the following points which are essential such as:

a) *ability to deal with geometrically complex models* – the developed models are required to obey laws which will be consistent within the environment. In the

[4] composed of tactile sensors which enable users to feel virtual object when a contact is made

example of a workstation, it is important that all the modelled parts, tools and buffers adopt rules which will make them respond and interact according to the norm.

b) *context sensitive behaviour* – implies behaviour which is dependent on the task at hand. In the example of the *Standard Operating Procedure (SOP)*, when a movement or gesture is required to be performed, it usually symbolises the standard procedure which will generate performance. Therefore it is important to have the capacity of enabling trainees to perform the exercise and evaluate their behaviour (body motion).

c) *achieving flexible visualisation* – requires having a virtual environment where the models are immersed and facilitates a deployment method which can manage the visualisation of those models at different angles – observing the VR environment through the trainee's eyes or as an assessor.

d) *a generic solution* – once models and rules are set up and the virtual environment defined, a generic solution can be generated to run a training session and can offer a better approach in the long term when modifications are required.

Finally Bright et. al. (2012) have investigated the use of a training simulator for urology and observed its advantages. Their aim was to explore technological improvement especially in terms of computer graphics. As for the training simulator, the VR system offers support for trainees in order to perform repetitively and not cause any damage to the on-going work in a workplace as well as providing performance feedback regardless of whether they were supervised. Moreover they added that training under the support of the VR system can shorten the learning curve, especially if the work procedure reveals to be complex, and can create adequate skills which can be transferable in a working environment (Brunner et. al., 2004). In this research several aspects need to be taught to trainees during a training simulation. Between *5S* and S*tandard Operating Procedure (SOP)* different knowledge and skills are developed. As mentioned in section 2.6, the lean enablers got their roots from the lean principles, principles which are originated from Japan, meaning that they include a work ethic and methods which are different to the western culture. Consequently, teaching the complex aspects of lean requires a system which can combine the theoretical and the practical aspects together in order to provide a full picture to a trainee for a better understanding and assimilation of the concept.

3.5.4 Application of virtual reality (VR) system

The VR system has been used as a support in diverse training programs such as simulators, health sector, teaching, etc... (Oliveira et al, 2007) and Hsiung et. al. (2011). The characteristics of virtual reality (VR) detailed in section 3.4.2 enable a learning program to provide users with fictitious visual, auditory and tactile senses as if they were in the real world. Virtual reality (VR) is a mediator between the virtual world, the real world, and the users, which can allow trainees a self-directed learning experience and practice (Chittaro & Ranon, 2007). Additionally the application interface brings together 3D models of real apparatus and a visualisation of physical situations in an interactive manner, users can experience direct contact with the virtual model and use their physical proprieties such as shape, size and time duration of an object and events, which can lead them to grasp the taught concept through a concrete perspective as opposed to solely theoretical (Kim et. al., 2001) and (Charyan et. al, 2011). Si and Yang (2012) made use of the system in a simulation program for green construction and aimed to establish a simulated environment which could provide an immersive feeling for the user and which could enable them to explore scenes and get the full view of the entire workplace in order to find problems and defects.

Bright et. al.'s (2012) work, which consisted of implementing a simulator for urology, has required the application of the virtual reality (VR) system. They run an experiment which was composed of 18 participants of different ages, both left and right handed and of different body sizes. It has been conducted in several simulation runs by altering the difficulty of the exercise in order to cover all the aspects of the urological operation. Visualisation facilities were implemented within the simulator in order to offer trainees the possibility of observing the 3D models in high quality and in several angles. As for the assessors, a visualisation tool was also implemented helping to monitor the evolution of the operation. The overall simulation provided positive outcomes among all of the participants in terms of delivering training to improve their understanding of urology. Due to the virtual reality (VR) system characteristics mentioned in section 3.5.2 which offer a practical side in training, trainees managed to improve their understanding and consequently showed an improved performance in their work after having a session. In this research, looking at both sides – theoretical and practical – the aim is to offer the capacity of providing explanations on the *5S* and *Standard Operating Procedure (SOP)* but also being able to challenge the trainee by simulating a particular situation and being able to capture the performance measures and consequently evaluate his or her understandings.

Chapter 4: Research Methodology and Experimental Design for 5S

4.1 Introduction

This chapter illustrates the methodology used to develop the training program for lean enablers – *5S* and *Standard Operating Procedure (SOP)*. As discussed in section 2.6, implementing lean requires a good knowledge from the staff members of any organisation, and a training programme can be an efficient learning tool to transmit the necessary skills and ensure a complete implementation of lean principles within a workplace.

The objective is to develop a virtual reality (VR) training program which can enable the virtual simulation of any working environment for the purpose of training the concepts of the lean enablers. It will include elements such as:

a) establishing the aim and the requirements of the training session with the use of a storyboard, flowchart and checklist,
b) setting up the structure to develop the 3D modelling elements for the virtual reality (VR) system,
c) implementing *"decision-making"* tools in order to support a trainee during a simulation run,
d) identification of the performance measures and implementation of an algorithm which will generate results,
e) development of a visualisation interface which needs to be part of the VR training program aiming to display the outcomes of a simulation run, and
f) running the experiments for *5S* and *Standard Operating Procedure (SOP)* in order to evaluate the efficiency of the method proposed by this research

In this section, the elements of the *5S* training program will be discussed, including the structure that requires to be followed when constructing the modelling elements, designing and implementing the *"decision-making"* tools and establishing the algorithm to generate the output results.

4.2 Overview of research methods

Research methodology is the path that leads any study to undertake appropriate and targeted measures to plan the research through gathering relevant information and carrying out experiments according to the initial objectives. Several types of research method are defined based on Yoshikawa et. al. (2008) such as qualitative, quantitative and triangulation.

4.2.1 Quantitative research

Quantitative research grows out of the strong academic tradition that places considerable trust in numbers with the purpose of representing opinions or concepts (Holsclaw, 2009). It is a research methodology used as part of scientific management, which consists of gathering numerical information through experiments, mathematical models, theories, hypotheses or analytical survey (Westerman et al, 2006). It is also defined as a method which consists of collecting concrete information which brings some sort of support to the development. The real data could be defined in several forms, for example performance measures or standard models with the objective of meeting the original goals of the research. Mantzoukas (2009) has defined different types of quantitative research:

a) experimental research which is based on analysis and hypothesis by comparing quantitative variables randomly and highlights an eventual relationship,

b) descriptive research defined as a type of research based mainly on collecting data with the purpose of testing hypotheses or answering questions on the studied subject,
c) correlation research focuses on determining a relationship between two or more quantifiable data, and
d) cause comparative research which looks at the cause and effect between quantitative data by comparing the values.

In this research, quantitative research is the appliance of methods to information collected through interviews, questionnaires and results collected by collaborators, where a large amount of the information is gathered and analysed with the objective of directing the research in an appropriate path in order to meet the requirements.

4.2.2 Qualitative research

Nastasi et al (2005) have defined qualitative research as a method which concentrates on words and observation to express reality, and attempts to describe information in a natural situation. Additionally it has being defined by Thomson et al (2011) as a method that collects non-numerical data. However, collecting quantitative data does not necessarily imply a quantitative data analysis. Survey research can just be interpreted qualitatively and include open-ended questions for data collection.

Levesque et al (2010) have defined two types of qualitative research such as:

a) “Exploratory research”; a type of qualitative research based on “resultant” research such as going over literature reviews, case studies or historical data with the focus on spotting eventual problems and leading the research towards setting up objectives. It may also provide a solution for when knowledge is limited in order to advance the research and allow a clear definition of the problem.

b) "Attitudinal research" is mainly oriented toward understanding and the evaluation made by people or a group of people. It leads towards a specific element of the research through opinions and beliefs constructed during:

   i. collecting qualitative data by conducting interviews, observations and group discussions,
   ii. description of the situation, work process and behaviour observation, and
   iii. analysing the information by identifying the problems within the sample of collected data.

In this research, the qualitative method is defined as theoretical assumptions of the interpretative paradigm. It is based on notions developed through subjective experience of people such as operators, managers, academics and specialists. The information collected through qualitative research can give an accurate description, decoding and interpretation of the meanings of phenomena behind a theory or an actual situation such as:

a) obtaining a realistic feel of a real situation which cannot be determined by the numerical data or statistical analysis,
b) gaining a flexible way to perform data collection, subsequent analysis and interpreting the collected information, and
c) acquiring the ability to understand the research subjects using their own language and terms.

4.2.3 Triangulation research

Nowadays the triangulation method is becoming more common in the world of research. Being able to collect information from multiple platforms can give a strong base for any research as explained by Vaivio and Siren (2010). It offers an interesting perspective on the research, by combining the numerical information collected through the simulation programme or statistical analysis, and subjective information mainly done by interviewing operators or managers and conducting a survey. In addition, Modell (2005) defines triangulation as a method which consists of establishing the research based on multiple data collection and technical analysis.

In this research, the triangulation method is defined as an information collection technique which consists of gathering data from different sources, quantitative and qualitative analysis such as real data, performance measures, but also interviews and subjective information such as the expertise of a specialist in a particular domain.

Three types of methodology are used as defined by Vaivio et al (2010);

a) triangulation which consists of gathering data coming from qualitative and quantitative research,
b) investigator triangulation which involves using more than one observer, interviewer, developer or data analyst to carry out an experiment. Confirmation of collected data among investigators by collaboration or discussion, leads the research to a greater credibility, and
c) theoretical triangulation that uses multiple theories or hypotheses consists of conducting a study with multiple perspectives and questions in mind. It could be

applied to test various theories by analysing information from the same set of data.

4.2.4 Developing research methodology

In this research, the triangulation method is used to collect all the necessary data for the purpose of designing and implementing the lean training program with different sets of runs.

a) Design of the storyboard

Storyboard is a method used in this research to help the understanding of the different training scenarios by breaking down the steps that need to be undertaken for each lean enabler. It was introduced by Smets et al (2010) as a tool that can describe in detail the entire work process or individual tasks to be completed. The description is mainly done through a series of images and written instructions which can give brief illustration on the specification, design and implementation i.e. total knowledge management solution. It can also include features such as individual frames containing the requirements of the content (Sadasivan and Gramopadhy, 2009). Smets et al (2010) show that a storyboard can be a stable learning support for any member of a team and describes it as a tool that allows an easy sketch design as well as an instructional model approach, including a resourceful learning theory level and multimedia collaborative approach. It has the potential to pass on information efficiently and improving the understanding of the main set of actions that need to be carried out as well as reducing the time taken to grasp the training scenario. In addition, it offers good flexibility such as bringing changes if necessary or redesigning another scenario which can be directed to a specific lean enabler training program (Yusoff and Salim, 2011).

b) Development of the Computer-Aided Design (CAD) model as part of the pre-process of the virtual reality system

Nowadays computer-aided design (CAD) model is considered to be one of the relevant methods to coordinate the 3D model between different system formats (Stark et al, 2010). In this research, each modelling element is developed as part of a pre-processing for the virtual reality (VR) training program and classified into a category which will be developed further. Using a CAD model can allow an:

i) advance visualisation of the design;
ii) easy grasp for complex modelling such as allowing creation of advanced 3D modelling and
iii) advantageous benefit as it is becoming a universally recognised engineering program, which can be a strong support when it comes to exporting a design into software like 3D Studio Max and then converting the model into another format such as a virtual reality (VR) format.

Johnson et al (2011) have studied the use of CAD models for educational purposes and evaluated the advantages and the facilities offered. The results of their studies show that CAD can:

i) reduce the time taken to design 3D models for the virtual reality (VR) environment
ii) facilitate the changing/editing of the model designed, and

iii) be applicable in other platforms by exporting the designed model to software such as;

- Pro Engineer software,
- 3D Studio Max,
- Virtual disk image (VDI) format converter software, which converts a 3D model design in 3D Studio Max into VDI which is the virtual reality system format.

4.3 Research Steps

In this research, the aim is to carry out the methodological steps in developing two lean enablers: *5S* and *Standard Operating Procedure (SOP)*. The steps established in this research go through a common procedure in building up the identified enablers or any new ones. Alternatively, other steps can be associated based on the nature of the enabler itself. Figure 4.1 shows the common proposed procedures that can be considered as a structure to follow in order to develop any virtual lean enabler environment.

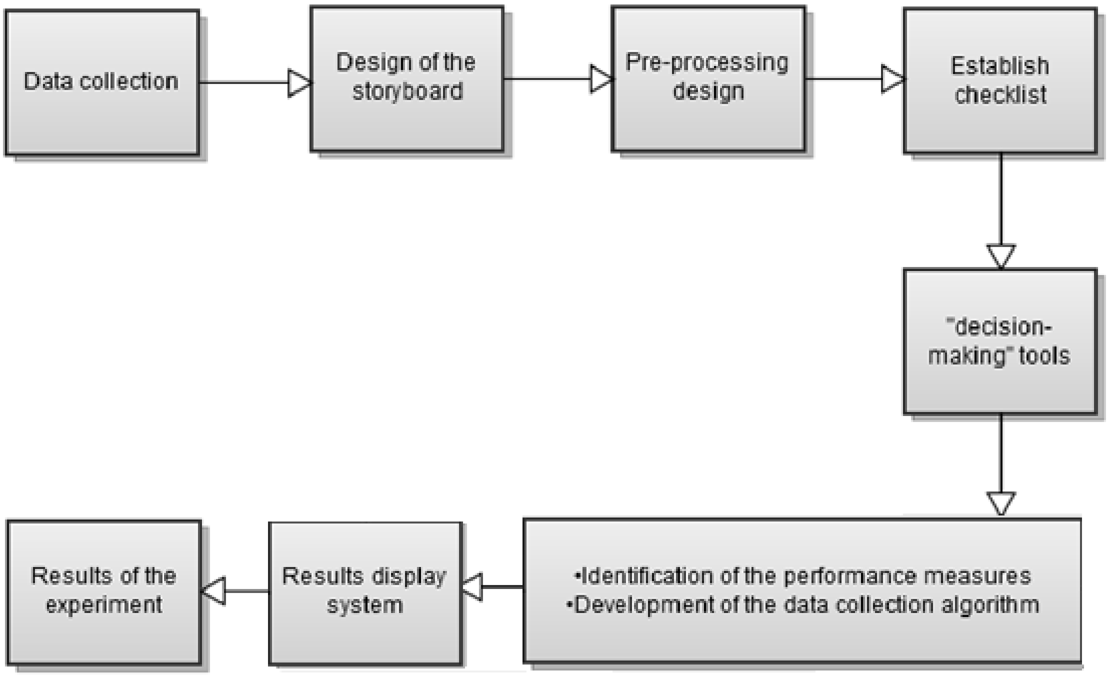


Figure 4.1: Common steps to develop the training program for lean enablers.

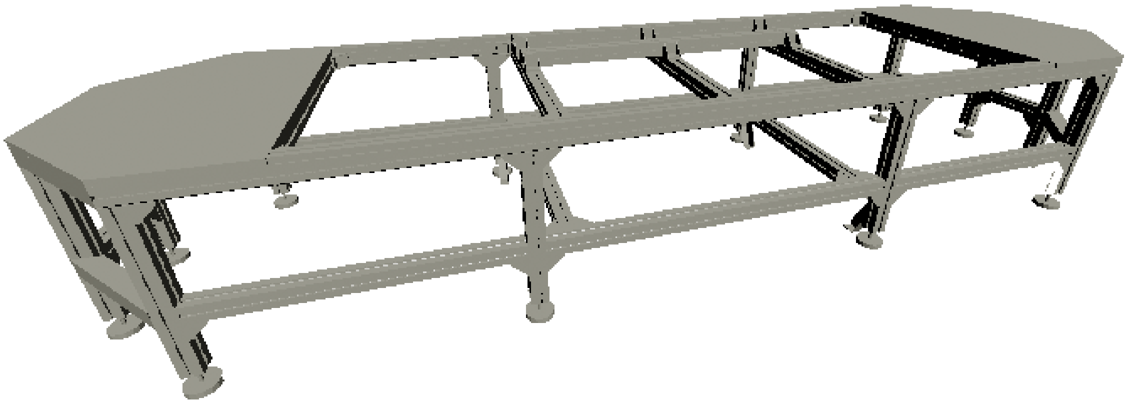
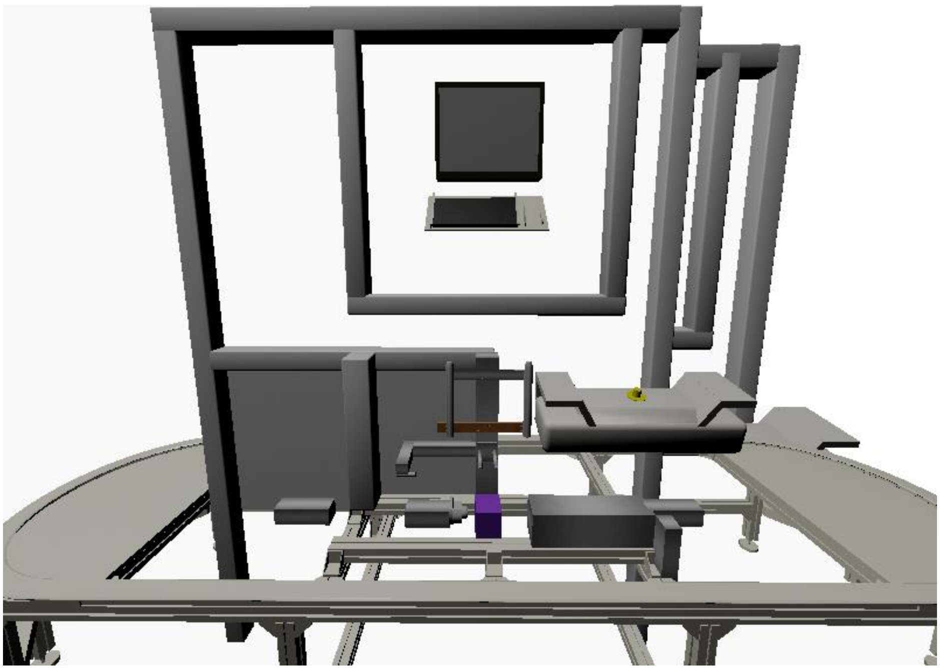
Lean enabler training 1: 5S

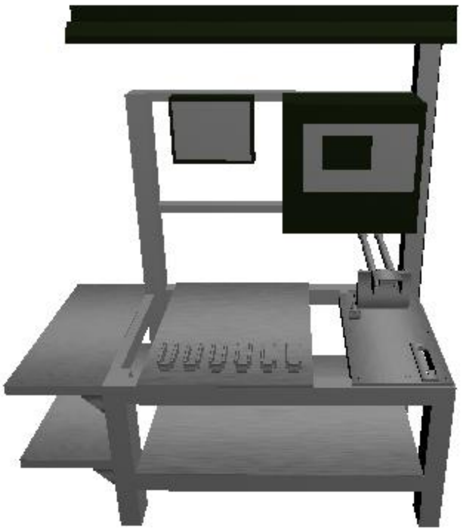
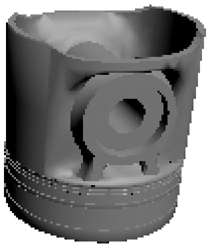
Step 1: Data Collection

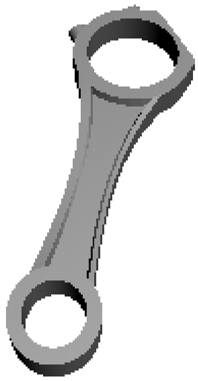
The data collected is provided by the Technology Strategy Board project -ref: K1532G. Part of the information is based on quantitative research by identifying the type of performance measures and reference models from one of the collaborators (Perkins Engine) to develop the training program – the 3D models were based on "*assembly machine for pistons"*. Additionally qualitative data is provided as the *5S* is studied and validated by the Technology Strategy Board collaborators to deliver specific performance measures after running the training simulation.

The models provided by Perkins were in a CAD format as shown in Table 4.1. They represent the main part of the workstation, which is currently used in Perkin's shop floor.

Table 4.1 CAD model of the "assembly machine for pistons"


Compressor workstation

Piston compressor



Piston slipper

Piston head



Piston body

Table 4.2 contains a set of performance measures have been provided by Perkins, which represent the outcomes of the workstation "*assembly machine for pistons*".

Table 4.2: Performance measure of the "assembly machine for pistons"

Performance measure	Values in percentage
% Blocking	2.8
% Waiting	1.17
% Working	96.03
% skills level	96

Step 2: Development of the storyboard

The storyboard is used as a visual aid to break down the *5S* procedure as illustrated in figure 4.2. To support the development of the lean enabler described in the storyboard, the flow chart presented in figure 4.3 details each part of the *5S* described in figure 4.2, in the form of a flowchart.

Figure 4.2: Storyboard of the 5S.

An analysis of the entire scenario defined in the storyboard is carried out where the steps are derived in the algorithm and contain aspects such as:

a) simplifying; looks at an alternative approach for organising a workplace through simplifying. It includes sorting out the tools with the use of a shadow board[5] and minimising excessive motion during production by assuring:
    i) tools, parts and equipment have designated areas. After using them, they should be returned to those designated places,
    ii) damaged equipment is not stocked in the shop floor, and
    iii) all utilised boxes or large parts have to be located outside of the working area and placed in a designated area,
b) sweeping; looks at the cleaning process of the entire working area. Each item, tool or work cell which is dirty, needs to be cleaned. Additionally the right cleaning material has to be used depending on the nature of the dirt,
c) standardisation; after establishing the new structure/layout of the workplace based on the *5S*. Signs and instructions need to be placed in the working area, so that staff members can get an understanding of the new changes brought about and then follow the new directions,
d) sustaining; based on a daily or monthly schedule, the objective is to leave the workstation in the same state as it was when *5S* was implemented. An indicative sign needs to be set up in order to specify instructions such as the free path, the location of tools and the overall sorting out of the work cell,

[5] A method used to organise tools within a workplace

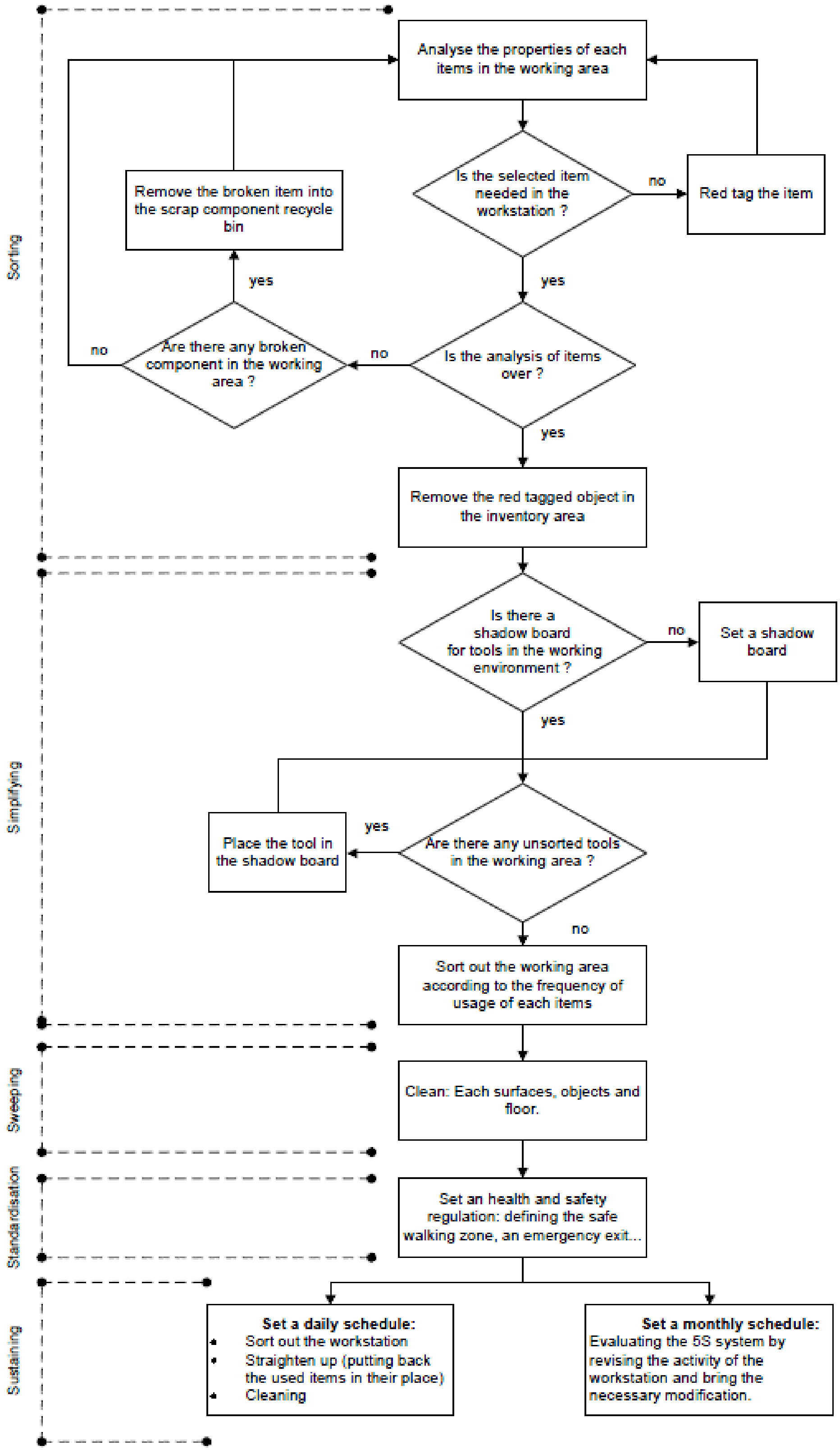


Figure 4.3: Steps of the 5S training program.

Step 3: Pre-processing design (CAD Model)

Part of the pre-processing design is to build the modelling elements for the training environment according to the data collection and the design described in figure 4.2 and figure 4.3. Each modelling element requires designing in 3D in order to symbolise, as closely as possible, the scheme of the storyboard. The features of the 3D models need to ensure an entire interactive system within the simulated environment and need to include information such as:

a) a model name,
b) the object type,
c) process animation that requires performing certain tasks, and
d) the affiliation/relationship between different modelling elements, and
e) the hierarchical statuses among the 3D elements.

Besides the 3D models, a C++ program is written which includes all the physical features of the 3D models, such as the properties of each virtual object and the interaction between the modelling elements, as well as between trainee and the virtual environment. Figure 4.4 illustrates the overall structure of the training program and how each part of the system is linked together.

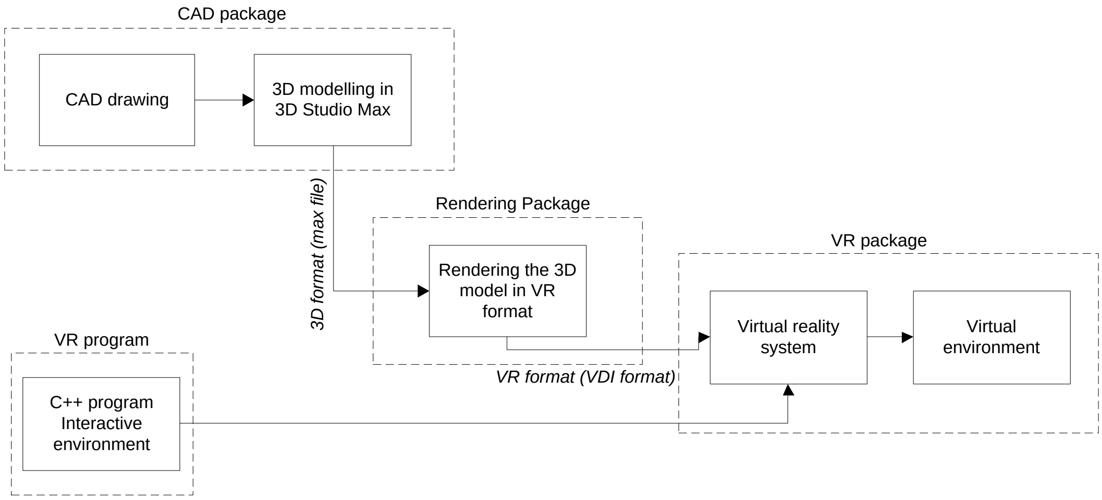


Figure 4.4: The work structure for the overall pre-processing design.

Step 4: Generate 5S Checklist

The checklist illustrated in appendix 1.1 can support assessors/trainers in monitoring the trainee's progression and in appraising their performance throughout the sessions. It represents the various activities to be undertaken and evaluates whether the trainee:

a) understands the concept of the *5S*,

b) takes the right decisions,

c) improves the performance measures, and

d) implements all steps correctly.

The composition of the checklist is made of sets of actions classified per category, where each category denotes the stages: sort, simplify, sweep, standardise and sustain. The evaluation of those actions is done by scoring them according to the understanding of the trainee using the evaluation ranking system described in appendix 1.1. The use of the checklist provides advantages in the design and enables the assessors/trainers to deliver constructive feedback based on the trainee's behaviour during the simulation runs.

Step 5: Development of the VR modelling element

The modelling elements are defined as an "object type" in the VR system as mentioned in step 3 and three types have been developed which are;

a) *Part* - a piece or segment of an object which can be used in assembly or subassembly (Duflou, 2011).
b) *Buffer* - defined as a resource which can be found within a workplace and has many potential functions related to machine reliability, batch size, flow of material (Yamamotoe et al, 2007).
c) *Tool* - device used to perform tasks (Buyurgan et al, 2004).

In addition to the type of object another aspect has been developed, the "movement type". It enables the manipulation of the 3D models with different movement properties, which are illustrated in table 4.1.

Table 4.3: Description of the movement types enabled within the virtual reality training program

a) "*Move*" is used when an object needs to be manipulated in any direction as long as it stays within the modelling environment and does not collide with another modelling element. b) "*Slide*" is used when an object needs to be transported from one point to another one as long as it stays within the modelling environment.

Step 6: Development of the decision-making of 5S training programme

Based on the checklist mentioned in step 4, "*decision-making*" tools have been designed with the objective of bringing awareness to the user during training simulation. Van Velzen et al (2011) have demonstrated the advantages of practical knowledge over theoretical learning through collaborative lesson planning, performing and evaluating. A similar method is applied in this research: the practical learning process is done through the virtual reality (VR) program by bringing the theoretical learning curve for the selected lean enabler with the practical side i.e. virtual reality (VR) environment. The "*decision-making*" tools are composed of multiple choices which can be used at each stage of the training exercise. Table 4.2 illustrates the different options developed.

Table 4.4: List of the pre-set actions for the 5S training programme within the VR system

Actions name		Symbols	Descriptions
Red tag	Tag item		Used to select unnecessary objects that need to be removed to an inventory point by red tagging them.
	Move tagged		Allows the user/trainee to automatically remove all the red tagged objects from the work station to an inventory point.
Scrap			When a used item is broken, "scrap" action sends it to the scrap identification recycling bin.
Mark areas			User/trainee can mark a selected area in order to standardise the workstation.
Clean	Oil		Used to clean the dirt originated by oil.
	Water		Used to remove water spilled on the floor or in working area.
	Floor		General cleaning action to clean the floor of the working station
	Shadow board		Allows the possibility of setting up a shadow board for organising tools

Arrange	Recycling bins		Imports recycling bins for the wastes
Properties			Allows visualisation of the information about any object in the virtual environment.

Gaoling et al (2010) have implemented a training program for manufacturing systems using virtual reality to teach users to assemble a mechanical part in a virtual world before performing it in the real world. The outcomes of their study show that the VR environment brings the user intensive feeling of immersion, which gives better results in terms of training. Benefits can be enhanced with the implementation of an interactive dynamic simulation to facilitate the planning, evaluation and verification of a mechanical assembly system. Similarly to what has been mentioned in table 4.3, a list of decisions is displayed for the *5S* environment, which represents a series of pre-actions developed to be used within the virtual environment. They perform a variety of tasks, from cleaning and moving materials to scrapping components. The purposes of the "*decision-making*" tools are to facilitate the manipulation and performance of tasks, which consequently can affect the output results depending on how they have been used. This aspect has been expanded on later in the research.

Finally table 4.3 represents the equivalent of the checklist mentioned in appendix 1.1 for the VR training program. In each stage of the *5S*, it describes the options to select from the "*decision-making*" tools which can enhance the implementation of the *5S* in the virtual environment as well as improve the performance measures.

Table 4.5: Steps of the 5S in the VR training

Elementary steps to be undertaken in 5S simulation programme	
Sort	Analysing the working area by identifying the usability of each item. **Action in the VR environment:** menu → properties
	Tagging unused items in red in the workstation **Action in the VR environment:** menu → tag
Simplify	The red tagged items have to be removed from the workstation and stored in an inventory place. **Action in the VR environment:** menu → remove tagged
	Organising the tools used in the workstation by setting up a solid organisation system with the use of a shadow board. **Action in the VR environment:** menu → shadow board
	Setting up a recycle system for the wastes with the use of recycle bins. **Action in the VR environment:** menu → recycle bin
Sweep	Tidying the shop floor by using the cleaning tool. **Action in the VR environment:** menu → cleaning floor
	Depending on the nature of the dirt in each area, use the appropriate cleaning tool. **Action in the VR environment:** menu → cleaning →"Choose the right tool"
Standardisation	Setting up rules for operators by clearly indicating the free path as well as separating the workstation from inventory **Action in the VR environment:** menu → mark area
Sustaining	Setting up an inspection to check that the standard rules set at the end of the training programme for the 5S is applied.

Step 7: Visualisation: results display system

The results display system can be an important part of a training programme when it comes to evaluating a session. Shiozawa et al (2010) have developed a data display to support assessors on the following statements:

- improving the analysis of the training session, by decoding information from the data,
- localising problems faced by the trainee during the evaluation, and
- the ability to provide constructive feedback after the training session.

In addition, Packham et al (2005) have adopted an interactive visualisation for evaluation and problem identification. Their visualisation system is based on providing several sets of results in different formats such as 2D and 3D graphs and digital results. “A data treatment program” has also been implemented in order to facilitate the analysis. In this research, a similar approach is undertaken; however the functionality of the results display system has more than one objective. It covers the principles developed by Packham et al (2005), particularly in underlining a problem happening during a training session, but also the ability to follow the progression of the trainee’s understanding during the session. Therefore two types of results display system have been developed:

a) First type: data display in the simulator

It is an inbuilt data display within the virtual reality (VR) program; as a performance indicator, it displays the essential data necessary for a trainee such as;

i) date and time: each training session is dated and the time is recorded with the results collected at the end of the training session,

ii) duration: the time taken to complete the training session. It starts when the session begins and run until the end, and

iii) task time: the time taken to complete one individual task. It is mainly affiliated with the decisions made in the training program. Depending on the decisions, the task time starts running and records the time taken to complete the particular decision selected.

b) Second type: Output results display

The aim of the results display is to support assessors/trainers in following the simulation session and monitoring the trainee's performance; it displays information such as performance measures in real time as the training is running. Depending on the lean training selected and the assessor's requests, the data is displayed at each step of the training. Different forms are enabled such as displaying digital values, graphs and representing results in percentages.

Step 8a: Identification of the performance measures

The performance measures play an important part in a training program in allowing trainees as well as assessors/trainers to observe and evaluate the results of the performance measures collected. The performance measures defined by Khalil (2005) have been used in this research to evaluate the performance of a trainee in a simulation run. They are composed of:

i) **% blocking**: represents the inactivity of a work centre where items are not processed due to not meeting the required conditions. This can be caused by a queuing or machine failure which can prevent parts either from getting to the work centre or being sent to the next work centre.

ii) **% waiting**: is the time taken by the preceding workstation to complete the jobs so parts can be sent to the next workstation to be processed.

iii) **% working**: is the percentage of time when machines are working.

iv) **% level of skill**: represents the understanding of a trainee in applying the taught concept in the workplace. It is expressed in percentage.

Step 8b: Development of the algorithm to generate performance measures

The structure of the VR training program is based on a *virtual training environment* – simulating a workplace and *results display system* – allowing assessors to visualise the results of a simulation run in real time. Within the VR training program, the structure of the working environment is based on several elements – *part*, *buffer* and *tool*. As illustrated by the flow chart in appendix 1.2 each one of those elements has been built with specific properties as described in appendixes 1.3 to 1.5.

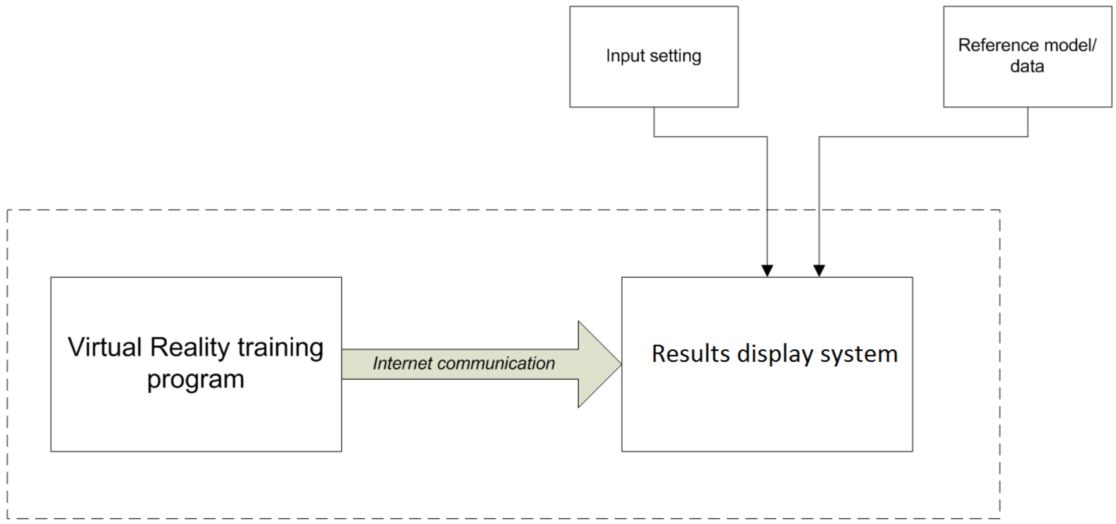


Figure 4.5: Overview of the interactive data displayer.

The design and development of the algorithm which allows the production of the performance measures for a simulation run under the VR training are composed of two parts which are:

a) capturing data about the layout of the workstations during a simulation run, and
b) comparing the collected data with the reference model in order to generate the performance measures.

Figure 4.6 illustrates the general procedure for generating the outcomes. The process of measuring the performance measure is linked with a reference model also mentioned in this research as a "*reference file*". It consists of storing the ideal layout of the working environment which is used during the simulation run to measure the current state of the virtual working environment, and consequently derives the performance measure. The reference model indicates the position in space of all items – *parts*, *buffers*, *tools* and *workstations*, but also detects the presence of *scrap component*, *shadow board*, *the recycle bin* and *the signs* set up as part of standardisation.

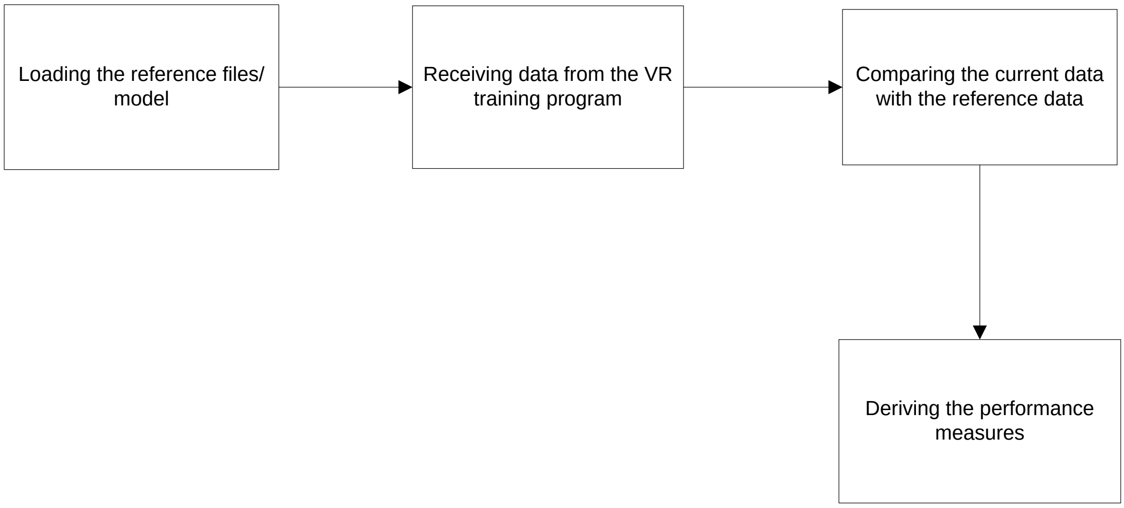


Figure 4.6: Development steps for displaying performance measures.

The algorithm is based on a comparative mechanism, it consists of collecting the data coming from the VR system program and comparing it with the reference data uploaded beforehand as described in figure 4.6. The results of that comparison generate the performance measures. The *reference file* represents the ideal working environment that a trainee is supposed to aim for when being in the training program. It contains the entire stages of *5S* methodology which include:

a) *object type* – elements which are essential for an effective process in the work station are represented, it includes:
    i) parts, including scrap component,
    ii) buffer,
    iii) tools, and
    iv) imported elements such as shadow board or the recycling bin.

b) *position in space* – each location of the object is recoved in the *reference file*, so results are being generated by comparing the state of the workplace with the reference model.

4.4 Results of the experiments

4.4.1 Description of the experiment:

The objective of the experiment is to investigate the teaching efficiency of a training program. The experiment runs by collecting and analysing data coming from the training program as well as going through a brainstorming session with the trainee in order to get the extra information crucial to complete the analysis.

The experiment is carried out three times. Different parameters are set up for each run as described in table 4.4.

Table 4.6: The composition of the 5S simulation experiment

First run: The *5S* simulation program is launched and the trainee is going through the principle without using any of the pre-set decisions offered by the training program.
Second run: The trainee applies the *5S* principle with the use of the pre-set decisions but without consulting the properties of each element within the simulation environment.
Third run: The trainee carries the *5S* exercise in the VR system by using all the pre-set decisions as well as consulting the characteristics of each object.

4.4.2 Display of the results:

i) Investigation of the performance measures at the sorting stage

The graph represented in figure 4.7 describes the progression of the performance measures at the *"sorting"* stage during the three simulation runs of the *5S* training program, based on the results illustrated in appendixes 1.6 to 1.8.

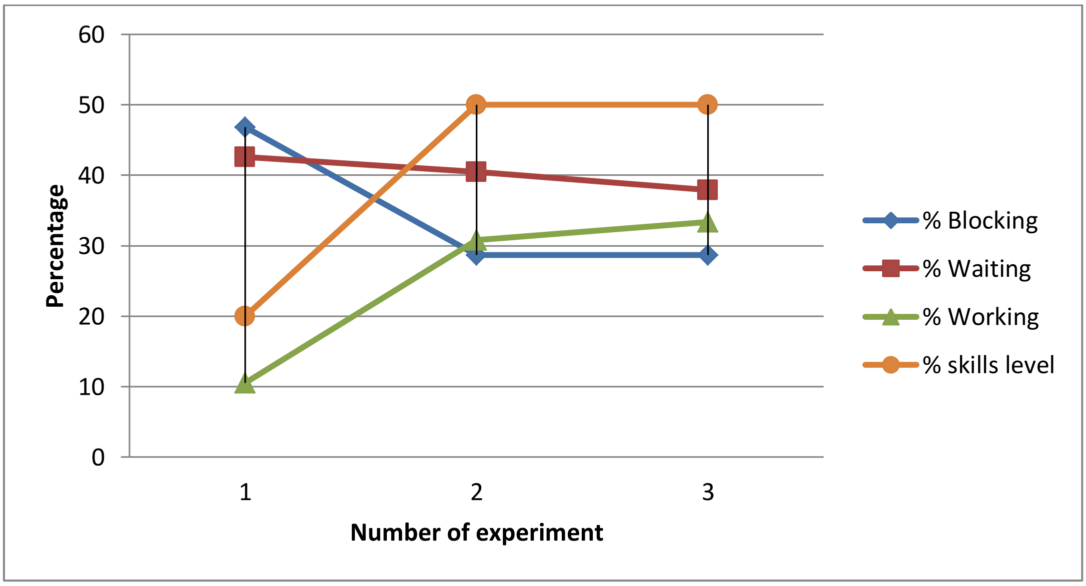


Figure 4.7: Results collected during the "sorting" stage of the 5S simulation run

The figure 4.7 displays the outcomes collected for *"% blocking"*, *"% waiting"*, *"% working"* and *"% skills level"*. Improvements in the performance measures (*"% working"* and "*% skills level"*) are visible when the trainee makes use of the *"decision-making"* tools while performing the exercise.

The results collected in the first simulation run translate the trainee's unawareness of the layout of the workplace and how to organise it in order to improve the work. Therefore the application of 5S was not well implemented which leads to poor results – where the workstation will face difficulty in meeting the delivery time and not meet the standard quality. However as the trainee goes through the second and third simulation runs, the errors committed in the first session were corrected and leads the trainee to sort out the workplace by analysing it at the start and then taking the appropriate decisions in order to re-structure the layout. Consequently the performance measures collected appear closer to the results described in the reference file, especially in the last simulation run.

ii) Investigation of the performance measures at the simplifying stage

In this section, the research looks at the progression of the performance measures at the "*simplifying*" stage of the *5S*.

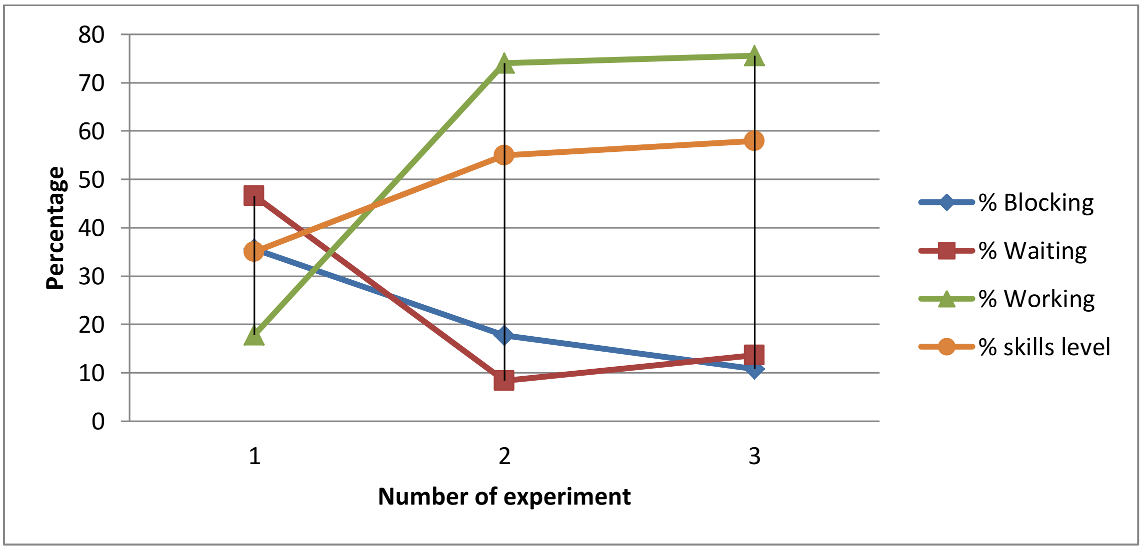


Figure 4.8: Results collected during the "simplifying" stage of the 5S simulation run

As described in figure 4.8, when the trainee does not make use of the *"decision-making"* tools, it leads to a poor understanding of the workplace; *"% blocking"* and *"% waiting"* are higher than *"% working*. However, when the trainee utilises the tools, then better results are obtained which leads to high *"% working"* and *"% skills level"* and low *"% blocking"* and *"% waiting"*.

In the simplifying stage of the 5S, the objective is to enable the accessibility of tools/parts, preventing loss/waste of time and making the work flow smooth and easy. By observing the results of the first simulation run, the results obtained are not meeting the standard quality which is described in the reference file of the training programme. Therefore the simplified workplace of the first simulation run can increase the risk of damage to items, not meeting the delivery time set by customer and low quality. Whereas in the last simulation run a clear separation is noticeable between % blocking, % waiting and % working – The outcome implies a workplace with a low risk of loss and wastes and better quality of items produced.

iii) Investigation of the performance measures at the sweeping stage

The next step looks at the progression of the performance measures at the "*sweeping*" stage of the *5S*.

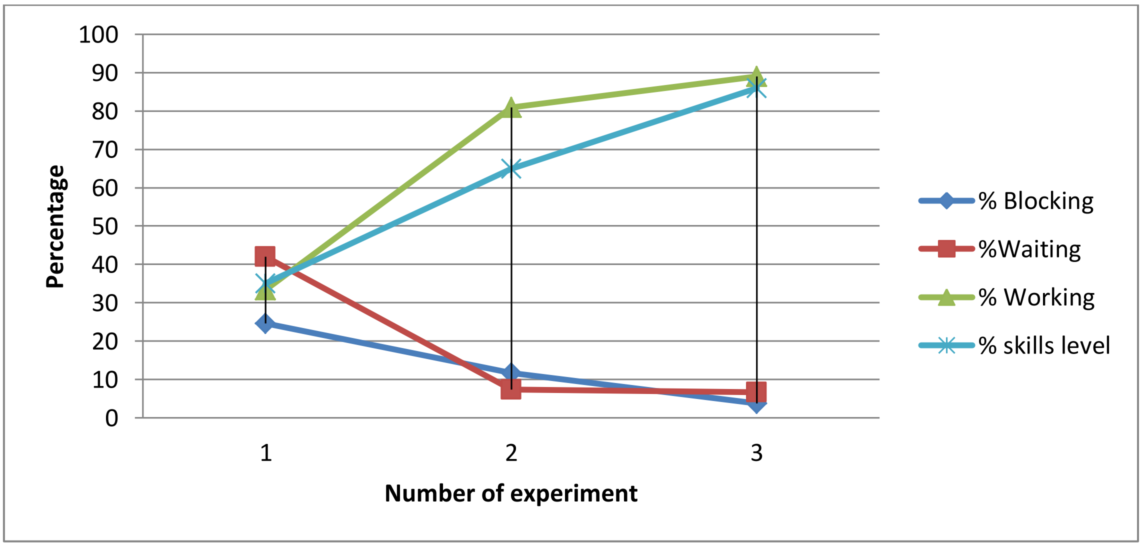


Figure 4.9: Results collected during the "sweeping" stage of the 5S simulation run

The *"% working"* and *"% skills level"* are at their peak, whereas *"% working"* and *"% blocking"* are low when the trainee consults the property of each element and consequently selects the appropriate tools for the cleaning process.

iv) Investigation of the performance measures at the standardisation stage

Finally the last interpretation of the results is the performance measures at the "*standardisation*" stage of the *5S*.

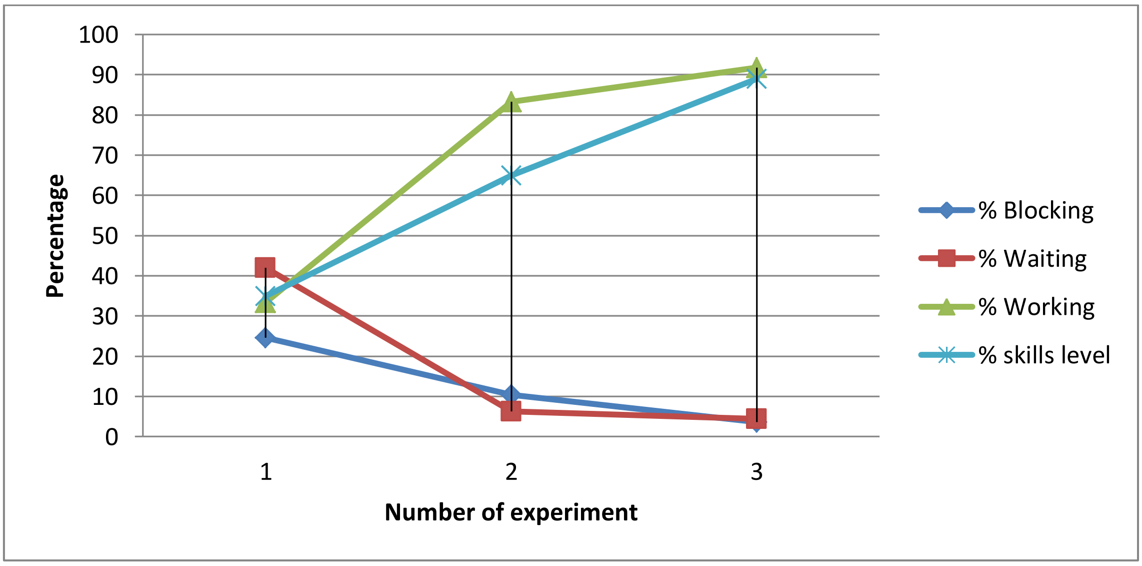


Figure 4.10: Results collected during the "standardisation" stage of the 5S simulation run

This is the last stage of a *5S* simulation run, and obvious difference is visible among performance measures with a low *"% blocking"* and *"% waiting"* and high *"% working"* and *"% skills level"*.

The standardisation stage aims to set up a working environment where high standards of housekeeping and workplace organisation such as cleanliness and orderliness are consistently maintained. Comparing the results obtained in the different simulation runs, especially between the first and the last run, they demonstrate a good understanding on the part of the trainee of how to apply the 5S. The results obtained in the third simulation run appear closer to the objective, especially with a low %waiting and blocking and high % working.

Chapter 5: Research Methodology and Experimental Design for Standard Operating Procedure (SOP)

5.1 Introduction

This chapter describes the development of another lean enabler, *Standard Operating Procedure (SOP)*. Defined in lean as a set of written instructions approved by specialists in charge, it describes a routine, or repetitive tasks carried out in a workplace. According to Song et al (2008), the *SOP* is an integral part of successful quality control that looks at providing sufficient support for each member of staff to perform a job properly and facilitate consistency in the quality and integrity of a product. The focus of this chapter is to establish with a structure to set up a training methodology for supporting the learning aspect of *SOP*. Each step of the development procedure for the training program is detailed, from the data collection through to the generation of results, including the development of the model as well as the *"decision-making"* tools.

5.2 Research steps for the Standard Operation Program (SOP)

The research steps for the *Standard Operating Procedure (SOP)* are developed based on the method mentioned in section 4.3, which elaborates each single stage of the development process from the data collection until the results analysis of the experiments.

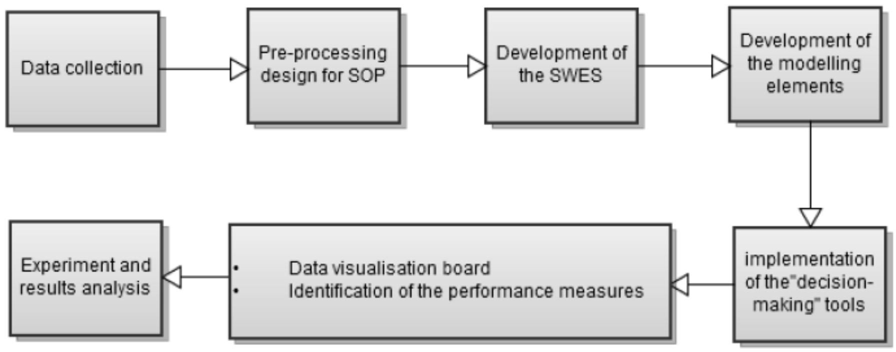


Figure 5.1: The steps used to develop the SOP program within a VR system.

Section 2: Development of the SOP training program

Step 1: Data collection

Data is based on quantitative research through gathering information for the development of the virtual model and establishing the steps undertaken for the assembly of a product provided by Caterpillar – *Fuel Filter*. The qualitative information has also been collected through meetings and informal discussion as well as each step of the development process having been validated and assessed/reviewed by the project collaborators.

A standard work element sheet has been provided by Perkins (illustrated in appendix 2.28) which describes the main assembly process of a fuel filter. This document has been used as a base in order to develop each model in 3D and used the sequence of assembly as a reference in order to evaluate a SOP training session under the VR system.

Additionally in Table 5.1, a set of performance measures have been provided, which contains the results related to “people”, “quality” and “velocity”. These outcomes will be used by this research as a bench mark to evaluate each simulation run.

Table 5.1: Performance measures of the fuel filter assembly

Performance measures	Values in percentage
People	96.3
Quality	93.4
Velocity	87.76

Step 2: Development of the storyboard

As it has been processed for the development of the *5S* in section 4.3, the collected information is combined with the support of a storyboard to organise the development of the training program. The work assembly are determined as part of the tasks to be performed according to a standard work description, also known in lean manufacturing as *Standard Operation Routine (SOR)* (Mager et al, 2007). When workers carry out tasks, the *SOR* gives the required sequence in which they can be performed in a given operation and at the operation level: it is the sequence in which personnel performs a series of operations. Three types of *Standard Operation Routine (SOR)* exist in the lean manufacturing (Mager et al, 2007):

a) "*a single repeated process*" – the prescribed instruction describes the sequence of a group of tasks to be performed repetitively,
b) "*a multiple repeated process*" – based on a prescribed sequence in which several operations are performed on a repetitive basis, and
c) "*a multiple non repeated process*" – defines the sequence of operation or tasks that vary throughout the day.

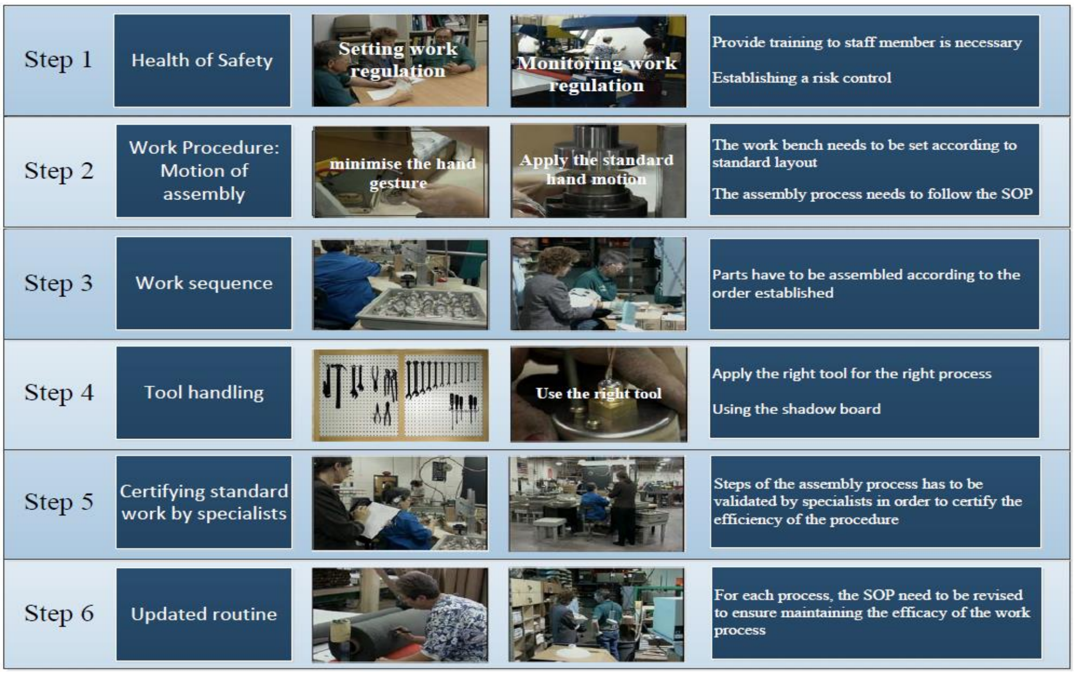


Figure 5.2: The Standard Operating Procedure (SOP) storyboard.

In this research, the assembly process described in the SWES provided by Perkins (appendix 2.28), describes a series of single steps to be performed in order to assemble the fuel filter, therefore "a *single repeated operation*" SOR type has been used to develop the training program. As illustrated in figure 5.2, the storyboard breaks down the different job tasks such as:

a) *Work sequence* – consists of assembly of an item according to steps described in the standard procedure,

b) *the hand motion* – in the *SOP* the hand gesture is standardised with the purpose of minimising excessive movement and consequently reducing waste motion,

c) *tools handling* – according to the nature of the activity, tools can be organised using a shadow board or other accessory such as trays, tools racks, etc.

d) *health and safety* – composed of sets of rules to ensure the health and safety of staff members during the production process.

Step 3: Pre-processing design

Part of the pre-processing consists of designing and developing the different modelling elements or objects that will be imported to the virtual environment. Therefore in this section, the focuses are made on designing the modelling elements according to the method which consists of:

a) collecting the required modelling elements designed in a CAD model.
b) elaborating the required animation for certain manipulations – some assembling processes such as screwing or fixing need to be represented in the virtual environment,
c) converting the model into virtual reality format, and
d) implementing the C++ program which includes the physical features of the modelling elements – the specifications of tools, parts and other elements developed in the VR environment.

Step 4: Development of the Standard Work Element Sheet (SWES)

A training programme may be a profitable investment that could be of benefit within a small or large organisation. Under normal circumstances, a training session contains four stages (Berkhof et al, 2011);

a) establishing a need analysis by providing trainees with the objective of the training session and the learning outcomes,
b) preparation of the session by giving the necessary information to the trainee, such as the instructions of the training program, the principles of the *Standard Operating Procedure (SOP)* and its objectives,

c) running the training session where the trainee carries out *SOP* tasks in a virtual environment, and
d) analysing the results of the session, where the trainers/assessors view outcomes of the program with all the required details for providing feedback.

The elementary aspect discussed in this stage is *the preparation of the training program*, where information is transmitted to the trainee. In lean manufacturing, one of the methods used to describe the standard work is through the use of different standard worksheets as listed in table 5.2. They provide staff members with written information on the assembly procedure.

Table 5.2: Types of standard work sheet use for SOP

a) **Standard Work Combination Sheet (SWCS)**: guide assessor by providing descriptive detail on operator's manner, through recording human and machine movements based on TAKT time, e.g. the demand rate of production, and shows the interaction between a single operator and a machine or more general a work cell (Black, 2007). b) **Standard Work Element Sheet (SWES)**: used as a support tool to analyse staff members' performance during a work shift or training simulation. The SWES is mainly used as a tool to set up instructions and explain how to carry out the standard work. Each step of the assembly process needs to include information such as (Lin and Yen, 2011); i) a description of each part, ii) the type of tool and how to use it, iii) the sequence of assembly, iv) detail on the hand motion during assembly process, and v) the health and safety issue. c) **The Standard Work Chart (SWC)**: a diagram which specifies the work sequence for one operator, details the work to be performed and includes the standard time (TAKT time) for each operation as well as a graphical representation.

For the purpose of this research, a *Standard Work Element Sheet (SWES)* is used in the simulation program as a tool which focuses on interaction between staff members and the working area. Each individual step is described as it may have specific and detailed instructions as shown in appendix 2.2.

Step 5: Development of the modelling element for VR environment

Modelling elements, also known in this research as "*objects"* within the virtual reality (VR) program, are built with the same structure mentioned in section 4.3. The purpose of the *Standard Operating Procedure (SOP)* varies from the objective of the *5S*. It is essentially based on manipulation through performing the assembly of an item. Consequently to be able to fulfil the requirements as listed in table 5.1, some modelling elements such as "*interactive zones*" and "*health and safety*" have been introduced.

Table 5.3: Types of modelling elements developed for the SOP training program

Modelling element	Description
Part type object	associated with the *"move"* type movement defined in section 4.3, parts are related to the elements that need to be assembled.
Interactive zone	is a boundary designed for each modelling element which; (i) indicates the beginning of an interaction and (ii) identifies the object to interact with.
Tool type object	the tool developed represents Allen keys in different sizes. The specification of each one of these tools is described in their respective properties.
Health and safety element	during the assembly process, all of the elements which represent the health and safety aspects in the virtual environment are described, such as the lighting or the secure device on the work cell.

The two modelling elements introduced into the *SOP* training program have the objective of enhancing the manipulation of 3D objects through allowing an interaction within the modelling elements and the possibility for the trainee to perform each stage of the assembly process according to the *SOP* principle.

a) As defined in table 5.3, each 3D object contains an interactive zone within the virtual environment. It is developed as a *support for assembly* aiming to help users perform complicated tasks in the virtual environment, through animations – an example of the interactive zone effect is when a *"screwing"* action needs to be performed: when the trainee takes a screw and the appropriate Allen key that matches the screw, it determines the beginning and the end of an animation where the conditions of execution are met; such as when an appropriate tool type object is coming into contact with a matching part type object.

b) The second modelling element introduced is related to the health and safety of the working environment as it is another important parameter of the *SOP*. As defined in table 5.3, the health and safety modelling element is oriented to provide a secure environment throughout the process by bringing awareness to the trainee on the different levels of caution in a workplace.

Step 6: Identification of the performance measures

For the purpose of generating the performance measures, the *SOP* training program needs to contain algorithms which will allow measuring parameters from the simulation run in order to derive the outputs. The parameters focused on by the VR training program are:

- **Motion –** *describes the hand motion during the assembly of an item* – the algorithm illustrated in appendix 2.1, records the hand motion by capturing the coordinate in space. The aim at this stage is to identify how the hands operate in the virtual environment when the trainee is performing a specific action in a defined area.

- **Work sequence** *–relates to the steps of assembly of an item* – each modelling element has a unique definition: composed by the type of object, its name, its specification and the order of assembly. The training program needs to evaluate the order of assembly based on the reference file. It generates an outcome expressed in percentage which indicates how much the trainee has been following the instructions specified in the *Standard Work Element Sheet (SWES).*
- **Tool Handling** – *symbolises the utilisation of tools* – aspects such as using the appropriate tool for a part and placing it back in its correct place are controlled by the program. The purpose of the "tool handling" parameter is to ensure the standard of work is respected.
- **Health and safety element** – *relates to the health and safety standards set up by the SOP* – defined within the VR training program, the *Standard Operating Procedure (SOP)* is composed of specific actions[6] which aim to symbolise the health and safety aspect of the work process. Based on the number of actions defined in the reference file (it is where the data for the *SOP* is saved and the program uses it as a reference to generate the performance measures), the program verifies whether those actions have been performed during the assembly.

Based on the parameters derived above, the *SOP* training program derives the performance measures at the end of each sequence of assembly as defined in the

[6] See appendix 2.2 for an example which consists of securing the item before starting the assembly

Standard Work Element Sheet (SWES) illustrated in appendix 2.2. The objective is for assessors/trainers to analyse the assembly process of a product, assess the performance and visualise the evolution through four types of outcomes which are:

a) People: health and safety**;**

Job descriptions are developed for each individual task/activity which take into account all aspects required to ensure a secure and trustable production (Saurin and Ferreira, 2009**)**. Rigas et al (2003) have looked at the health and safety aspect and demonstrated that it depends strongly on the operators' understanding of the eventual hazardous risks which can be linked with the workstation and the use of equipment or other elements designed to ensure the safety of the production.

Consequently the health and safety precautions in this research are strongly related to the work procedure as illustrated in table 5.3. To evaluate the safety of a production, it is vital to look at the ability to use the right tools and understand the importance of standard procedure adherence. Consequently the relationship developed and which composes part of the algorithm for generating results is;

People (health and safety) = health and safety element + tool handling

b) Quality: quality of production based on customer demand

The performance measure *"quality"*, related to the production quality, measures the conformity of the production according to the specification required from customers (Han and Park, 2002). Nejjar (2011), Garcia et al (2012), Lin and Pearn (2011) and Hon (2005) have looked at the quality process within organisations and classified the characteristics of the quality production in a workplace. The improvement of the work and reduction of wastes have been highlighted as part of the quality production features.

In the research scope, quality is partially influenced by the order of assembly which has been designed to provide the best method of assembling an item by generating the best quality for the customer’s requirements and increasing the production yield. The second parameter to generate quality is focused on the waste motion, e.g. reducing excessive hand movement during the assembly process which can increase production time as well as reducing the quality of product. Consequently the relation for quality which combines the work method and waste reduction is:

$$Quality = Hand\ motion + Order\ of\ assembly$$

c) Velocity: process time

The process time is seen as the time taken during which the material is being changed e.g. machining the operation or an assembly (Chincholkar, Herrmann, 2008). In this research, process time also known as *velocity*, is seen as the time taken to complete a task during the assembly process of an item. The outcome that represents velocity, describes the improvement of the process time expressed in percentage. The algorithm generates the result by comparing the time taken to complete a job with the process time in the reference file.

d) cost;

The performance measure *cost* is related directly to the production cost of a single item. It is affected by different factors, such as quality of production, the Standard Work Elementary Sheet (SWES) and the behaviour of personnel (Gamberi et. al., 2008). Cost is one of the important outputs measured in the Standard Operating Procedure (SOP) (Ozbayrak et. al., 2004) and (Roy et. al., 2008). However for the purpose of this research the output cost stands outside of the scope and therefore it is not been taken into account.

Step 7: Development of the "decision-making" tools within virtual reality (VR) training program

Despite the limitations linked with the virtual reality equipment, mentioned in section 5.2, step 3, *"decision-making"* is implemented within the *SOP* in order to offer an element of support for the training program which includes:

a) consulting the features of a particular modelling element such as the modelling element type, the last time that the modelling element was used and the frequency of usage, and

b) supporting trainees with complicated/unachievable manipulation (due to the VR equipment limitation) such as placing a part type object inside of a buffer type object or utilising a tool type object to screw a part into another.

Table 5.4: List of the "decision-making" tools developed for the SOP training programme.

Actions name		Description
Tool	• Allen Keys M3 • Allen Keys M4 • Allen Keys M5 • Allen Keys M8 • Allen Keys M9	Allows the trainee to select the appropriate tool to process the assembly of the item. Allen Key is an "L" shaped tool consisting of a rod having a hexagonal cross section, used to turn a screw with a hexagon in the head. The "M" letter represents the size of the tool.
Secure Parts	• Close arms • Open arms	Being part of the health and safety aspects of the *SOP*, it enables the securing of the chassis of the item on the work bench during the assembly process. Two actions are available.

Rotation holder		Enables the turning of the work bench where the chassis is fixed in order to facilitate observation of and the assembly process of the item.
Light	• Turn light on • Turn light off	Allows the switching on and off of the lights in the work station – one of the health and safety aspect procedures of the *SOP*
Properties		Allows visualisation of the information about any object in the virtual environment.

Step 8: Data generation algorithm and the results displayer

An algorithm is developed to generate results based on the input parameters. The performance measures defined in step 7, section 5.2, are quantified during the simulation session according to the performance of the trainee. The algorithm is written in C++ program, which is defined in appendixes 2.19 to 2.24.

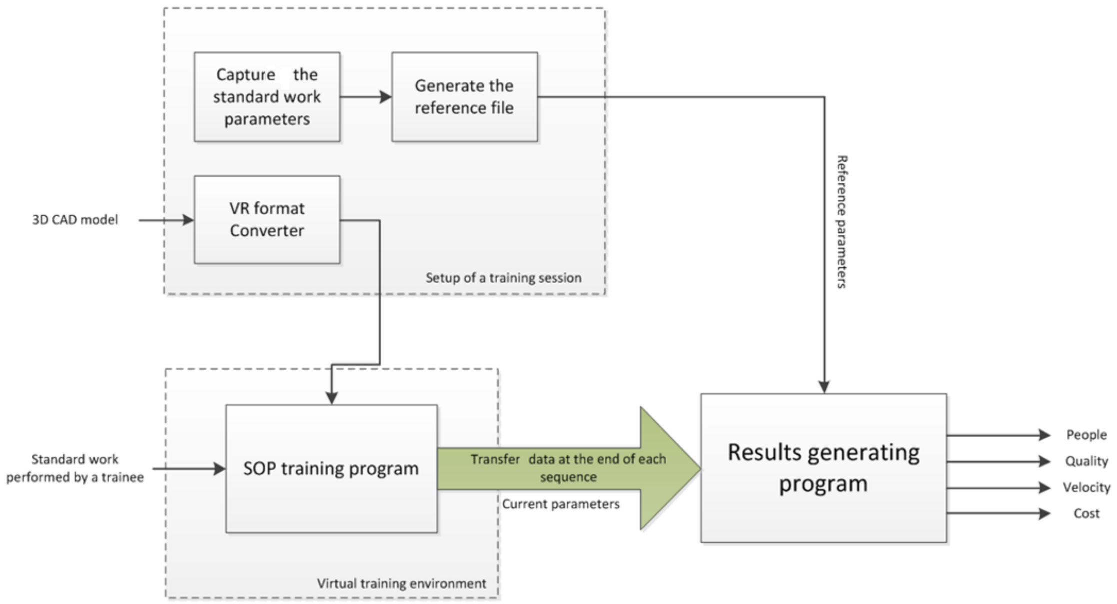


Figure 5.3: General structure of the SOP training program.

As it has been done for the *5S* training program mentioned in section 4.3, the principle of generating performance measures is based on comparing two types of data – the *reference* data and the *current* data. The reference data contained in a file represents the ideal work procedure to assemble an item symbolized in the virtual environment. Once the modelling environment is defined and loaded in the training program, the reference file is created using the virtual reality (VR) system. Each step of the assembly process is constructed by capturing the correct assembly procedure, which is:

a) The standard hand motion to adopt during the assembly process,

b) The order of assembly for each part,

c) The tool handling, and

d) The processing time for each step of the assembly process.

During the simulation run, the four parameters are sent into the results generation program at each stage of the assembly and by comparing those parameters with the standard parameters defined in the reference file, the performance measures are generated.

5.3 Running the experiments for SOP training program

The experiment consists of analysing the effects of the input parameters mentioned in step 2, section 5.2, on the output results of the *SOP* training program illustrated in step 7, section 5.2. Each experiment is conducted to generate a set of results. Based on the combination of the input parameters described in table 5.5, the experiments aim to evaluate the *SOP* training program, especially the effects of the decisions made. They are composed of sixteen simulation runs where all the possible combinations of the input parameters have been taken into account. The experiments are conducted with the help of 16 participants, especially students and staff member of Perkins. Each simulation described in appendix 2.29 are designed to emphasise one or several input parameters of the standard operating procedure and provide instructions and tips to the trainee in order to ensure that the appropriate guidance has been followed correctly. The input parameters are composed of four elements, which are “health and safety”, “work sequence”, “hand motion” and “tool handling” as described in table 5.5 and the output results are generated for each step of the assembly process and they have been attached in appendixes 2.3-2.18. In table 5.5, the average values of the output results are calculated for each run.

5.3.1 Steps of the experiments

a) Design of the training environment

The VR training program includes a user interface which allows the assessors/trainers to define the training environment, either by importing 3D models from CAD design or re-arranging an existing model stored in the library of the training program. With the use of the *“edit mode”* of the training program, the working environment can be defined in order to suit the trainee’s professional background and load the virtual environment.

b) Define the *Standard Operating Procedure (SOP)* within the training program

The *SOP* needs to be defined using a *reference file* which can be created through the VR training program. Using the *“Capture reference”* mode of the results display interface, the assessor/trainer performs the assembly process ensuring they capture the whole procedure of the work standards described in the *Standard Work Element Sheet (SWES)* illustrated in appendix 2.2. Consequently all the information such as the four parameters defined in section 5.2, step 2, are collected by the program and saved in a file at the end of the procedure.

c) Run the simulation model

In order to start the simulation, it is important to ensure the reference file which corresponds to the modelling environment is selected. The simulation run consists of executing the experiment based on the input parameters defined in section 5.2, step 3. Those parameters symbolise the method used during the assembly process.

d) Results collection

The results of the experiment are collected for each simulation run in excel format which includes all the results of the performance measures at each stage of the assembly process.

5.3.2 Display and analysis of the output results

The four parameters mentioned in section 5.2, step 2 are used in this experiment as inputs. Sixteen simulations runs have been performed which take into account all the possible combinations of the inputs as defined in table 5.5. In order to visualise the effect of the decision made on the outcome for each experiment, the results illustrated in appendixes 2.3 to 2.18 have been collected for every simulation run and an average value of performance measures has been calculated.

Table 5.5: The results of the Standard Operating Procedure training program evaluation

Input parameters					Output results (%)		
Number of run	**Health and safety**	**Hand motion**	**Work sequence**	**Tool handling**	**People**	**Quality**	**Velocity**
1	0	0	0	0	0	13.36	23.14
2	0	0	0	1	26.45	17.44	21.86
3	0	0	1	0	0	28.82	25.54
4	0	0	1	1	38.71	39.34	43.10
5	0	1	0	0	0	36.04	16.93
6	0	1	0	1	29.83	37.69	23.14
7	0	1	1	0	0	75.36	58.28
8	0	1	1	1	39.91	75.36	66.61
9	1	0	0	0	47.38	25.68	23.95
10	1	0	0	1	83.44	28.93	27.59
11	1	0	1	0	51.34	35.54	24.89
12	1	0	1	1	87.87	49.43	57.80
13	1	1	0	0	59.75	48.68	43.65
14	1	1	0	1	87.24	54.47	65.34
15	1	1	1	0	59.51	71.26	66.84
16	1	1	1	1	93.06	85.42	79.76

N.B. In the input parameter, the value "1" means "method applied" and "0" means "method not applied"

To be able to analyse the effect of the input parameters, the data is reorganised in order to facilitate the observation. As detailed in table 5.6, the results have been classified in three categories, which are;

- executing the assembly work without considering *SOP* principles; all aspects of the standard procedure described by the *Standard Work Element Sheet (SWES)* are dismissed,
- performing the assembly process with a partial implementation of the input parameters. For each run of the simulation model, part of the elements described in SWES are taken into account, and
- total implementation of the principles consists of running the simulation model and ensuring the implementation of the entire procedure as indicated in the SWES during the assembly of the virtual item as illustrated in section 5.2, step 5.

People	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Health and safety and tool handing are not taken into account	0		0		0		0									
Health and safety or tool handing is taken into account		26.46		39		29.83		39.91	47.38		51.34		59.8		59.51	
Health and safety and tool handing are taken into account										83.4		87.87		87.24		93.1
Quality																
Hand motion and work sequence are not taken into account	13.4	17.44							25.68	28.9						
Hand motion or work sequence is not taken into account			28.82	39	36	37.69					35.54	49.43	48.7	54.47		
Hand motion and work sequence are taken into account							75.4	75.36							71.26	85.4
Velocity																
None of the input parameters are taken into account	23.1	21.86	25.54		17				23.95							
Part of the input parameters are taken into account				43		23.14	58.3			27.6	24.89		43.7			
All the input parameters are taken into account								66.61				57.8		65.34	66.84	79.8

Table 5.6: Reorganisation of the results according to the level of implementation of the SOP

a) Analysing the evolution of "*people*" according to the implementation of the SOP principles.

The results described in Figure 5.5 are related to "*people*" and they were collected during several experiments where in each experiment a unique instruction was established in order to ensure that the trainee would apply the appropriate approach in order suit the purpose of the experiment. Those instructions are described in appendix 2.29.

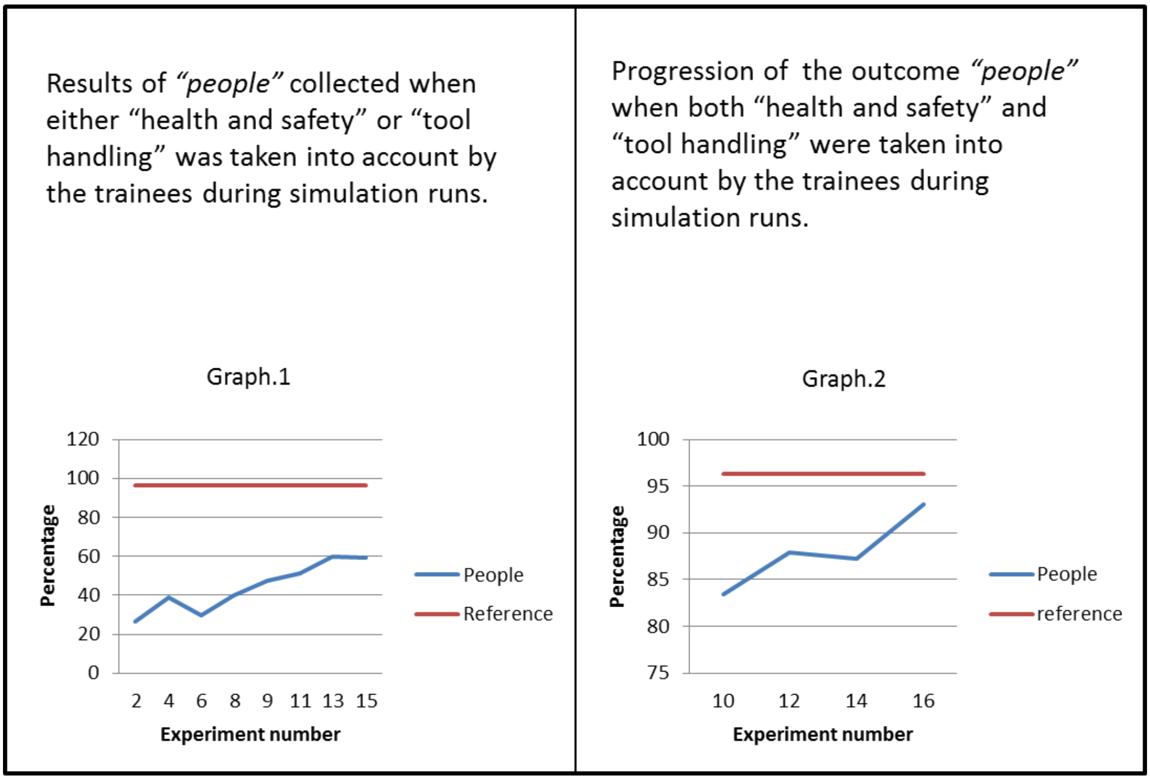


Figure 5.5: Progression of the output related to *"people"*

The results collected for *"people"* are coming from the experiments where only one of the parameters ("health and safety" or "tool handling") was correctly applied by trainees during the several experiments run. Therefore in Graph.1 of the figure 5.5, the results vary between 20% and 60%. Comparing the results with the reference value, which corresponds to the outcome obtained by a specialist, the lowest margin (corresponding to the difference between the highest results obtained and the reference) is 36%. Whereas the highest margin (the difference between the smallest result obtained and the reference) is 69.84%. The results obtained demonstrate that trainees who went through the simulation run did not make the appropriate decisions and therefore implemented the steps related to “health and safety” and “tool handling” inefficiently or only partially. Consequently the performance measure “people” obtained does not correspond to the outcome in the reference file.

In the category of the experiments where trainees applied both parameters, “health and safety” and “tool handling”, the average results obtained (87.9%) are highest than the results displayed in Graph.1 (44.15%). Moreover the lowest margin in Graph.2 is 3.2%, whereas the highest margin is 12.9%. These obtained outcomes translate a good understanding from the trainee about the “health and safety” elements and how to handle tools while performing the work. The appropriate decisions were undertaken and the steps described in Standard Work Element Sheet (SWES) were applied accurately, and consequently the outcome obtained tended to match the reference.

From these results, an improvement can be observed, especially on the performance measure “people”. Some elements linked to health and safety were described in the Standard Work Element Sheet (SWES) in appendix 2.2 with the aim of ensuring that the work will be conducted by the trainee in a safe way, and the training program was designed to look at these aspects of the SOP. Therefore whenever the trainee missed applying the standard described in the SWES, it automatically impacted on the result.

Having a system that displays outputs in real time and that is responsive to the interaction and decisions made by the trainee can improve the learning curve. The training program has been developed with the aim of being as close as possible to a real work environment and to correlate the results of a training session with the outcome obtained by a specialist of the work station. This puts the trainee to work in realistic conditions and therefore highlights the importance of the SOP at work.

b) Analysing the evolution of "*quality*" according to the implementation of the SOP principles

In a similar way, the results related to *"quality"* have been collected while conducting the sixteen experiments described in table 5.5. Each trainee went through the simulation runs and followed the appropriate instruction detailed in appendix 2.29. The objective was to observe the progression of *"quality"* and how the parameters (*"hand motion"* and *"work sequence"*) affect the result.

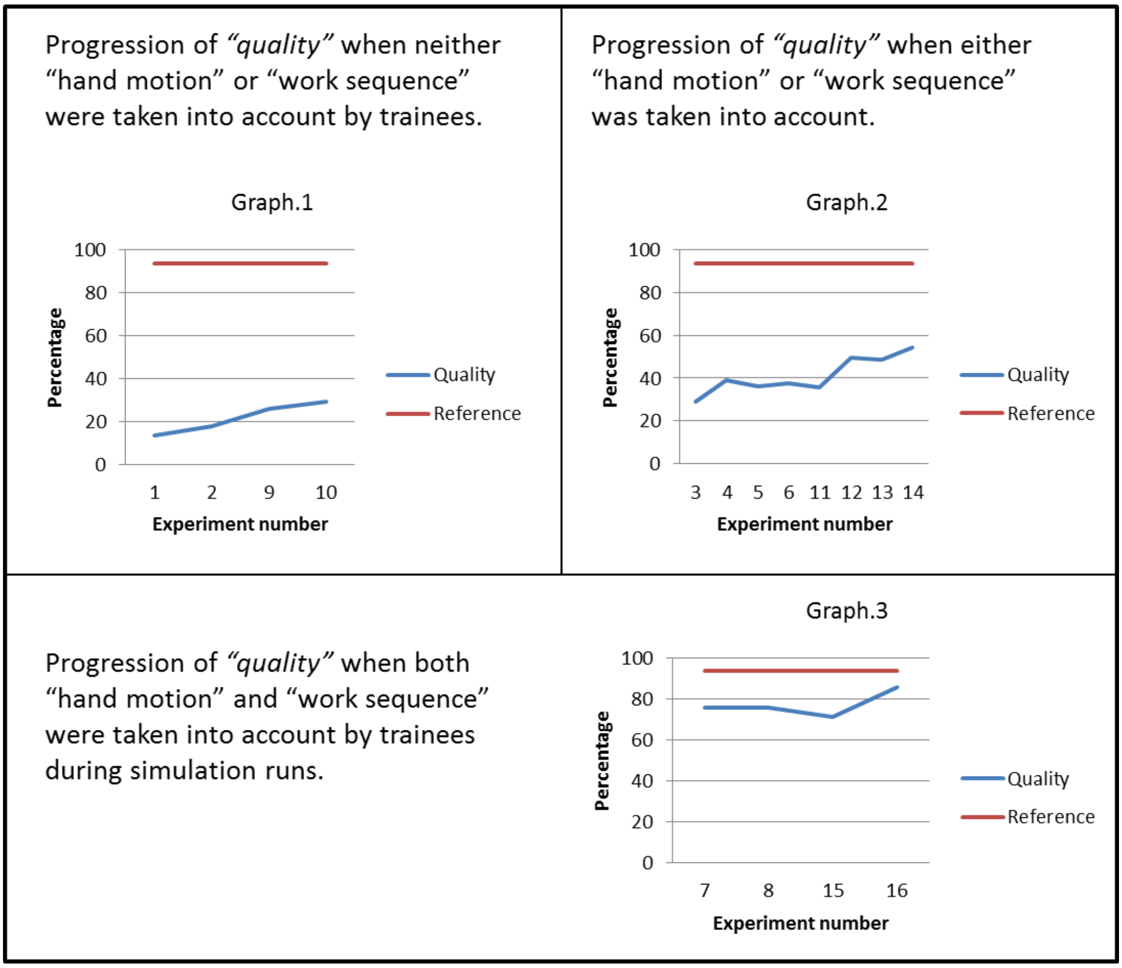


Figure 5.6: Progression of the output related to *"quality"*

The Graph.1 in figure 5.6 describes the evolution of *"quality"* during the experiments where neither of the parameters (*"hand motion"* or *"work sequence"*) was applied by the trainee. The average value of the results in Graph.1 is 21.35%. As for the highest margin, corresponding to the difference between the lowest value of *"quality"* obtained and the reference, the value is 80%, whereas the lowest margin, which is the difference between the highest values obtained and the reference, is 64.5%. The experiments' low outcomes are mainly related to a poor understanding of the standard by trainees. The decisions made in the experiments 1, 2, 9 and 10 were not appropriate and did not follow the standard described in the SWES.

In Graph.2, the average value of *"quality"* obtained is 45.66%. As for the highest margin, the value is 64.58% and the lowest margin is 38.93%. During the experiment stated in Graph 2, trainees understood the aim of the SOP and managed to implement some of the steps. However their understanding remains partial and therefore the decisions undertaken did not entirely follow the description in the SWES. An improvement is noticeable when the results are compared with those in Graph 1; however they are still only midway towards the reference.

Finally in Graph.3, the average value derived is 76.85% and highest margin derived is 22.14% and the lowest is 8%. From the above observation, the results displayed in Graph.3 are closer to the reference then the other two graphs. These results in experiments 7, 8, 15 and 16 prove a good grasp of the *Standard Operation Procedure (SOP)* by the trainees. They have managed to understand the purpose of the SWES, especially in adopting the correct *"hand motion"* and ensuring the *"work sequence"* is respected in order to complete the work successfully. In the SWES, the work sequence has been established, which maximises the efficiency of manufacturing the item and minimising the wastes. In the description part of the SWES, emphasis is made on applying the correct hand motion. Indeed, it is crucial in a production line to ensure operators keep their job as efficient as possible and avoiding working outside of the assembly procedure as it can increase *"over motion"*, *"transportation"* and also affect the quality of the production. Therefore, during these experiments, the trainees have respected the standard and ultimately have improved the quality of the manufactured product.

c) Analysing the evolution of "*velocity*" according to the implementation of the SOP principles

The last analysis conducted in this chapter is related to *"velocity"*. As opposed to *"people"* and *"quality"*, *"velocity"* looks at all the parameters, which are *"health and safety"* elements, *"work sequence"*, *"hand motion"* and *"tool handling"*. Therefore during the experiment runs, the SOP training program evaluated how the trainee performs through these parameters and consequently derived the results at end of each work sequence.

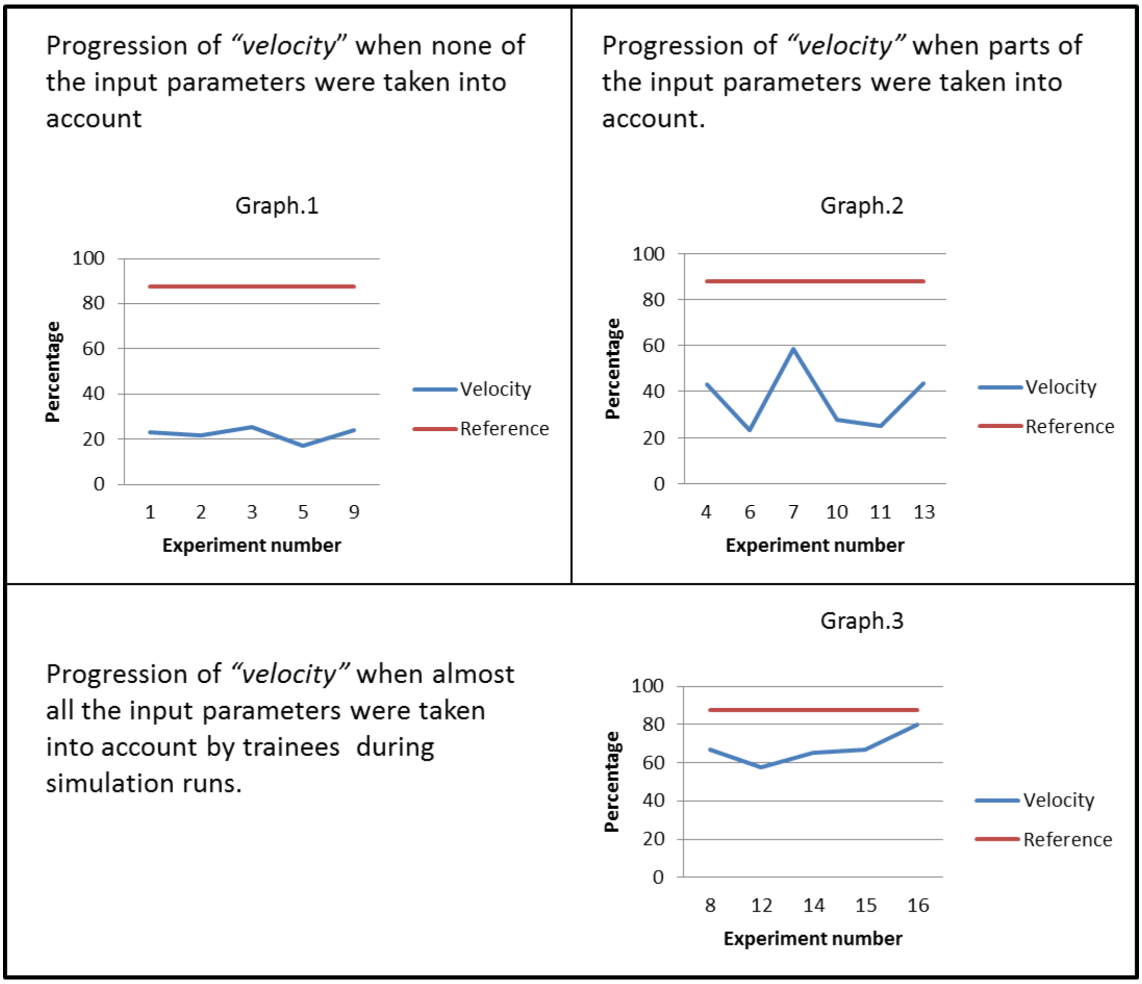


Figure 5.7: Progression of the output related to *"velocity"*

The Graph.1 in figure 5.7 describes the progression of *"velocity"*. It corresponds to the experiment category where trainees did not follow the Standard Work Element Sheet as part of the work standard and therefore missed applying the main parameters which are associated to SOP. Consequently the decisions made by the trainees increased the time taken to complete the task, which led to an average value of 22.29% throughout the five experiments. The highest margin related to *"velocity"* displayed in Graph.1 is 70.76%, whereas the lowest margin is 62.22%.

In Graph.2, the average value of *"velocity"* obtained is 36.77%. As for the highest margin, the value is 64.62% and the lowest margin is 29.48%.

Finally in Graph.3, the average value derived is 67.27% and highest margin derived is 29.96% and the lowest is 8%. Moreover, experiment 16 has been conducted with a trainee following the standard written in the SWES accurately and ensures that all parameters have been applied correctly. The high result obtained in experiment 16 is mainly due to the fact that the *Standard Operating Procedure (SOP)* tends to optimise the time taken to complete a job, therefore when the trainee accurately follows the steps in the SWES, he/she is working in an optimum way.

d) Conclusion drawn from the results

One of the concerns highlighted in section 1.2 was the difficulty in preventing damages during the on-going work while training staff members. The approach proposed in this research stands on a structure, which enables a flexible work environment as described in section 4.3 and 5.2. This method offers the possibility of setting up a desired work environment in order to suit the requirements of a training session and ensure that all subtle aspects of the real work environment are implemented. Ultimately the trainee has the opportunity to go through the entire process of the SOP and grasp some of the key aspects of it, such as the importance of health and safety while doing the work, and following the appropriate procedure.

Another point was mentioned in section 1.2, which was related to evaluating the performance at an individual level and providing sufficient feedback and guidance in order to improve the learning curve. The VR training program is designed with the vision of focusing on one trainee at a time and ensuring that the *Standard Operating Procedure (SOP)* is grasped properly. Another focus of this research was to provide a training program which can offer support to trainers/assessors by enhancing the evaluation of a training session. The results visualisation that comes with the VR training program has been used during the experiment and offered the possibility of observing the progression of the performance measures in real time while the training was going on, but also enabled the accurate measurement of some of the key factors for the SOP such as the hand motion of the trainee while performing the work, or the utilisation of tools.

Finally the *"decision-making"* aspect was one of the main factors along with a flexible training environment and results visualisation interface. The objective of these experiments was to evaluate the robustness of the proposed method when it comes to generating the performance measures according to the decisions made by the trainee. From the start until the end of a training session, the program evaluates each step of the assembly procedure by using performance measures obtained by a specialist as a reference. This offered a realistic approach as to how the work needed to be completed and challenged the trainee to follow the instructions of the Standard Work Element Sheet (SWES) accurately.

Chapter 6: Discussions

6.1 Introduction

Based on Perrin et. al. (2012), being the leaders in a specific field is becoming one of the common long-term goals shared by many large organisations in the global market. One of the strategies to stay ahead of the competition is to invest in activities that improve production such as training programmes (Tan et. al., 2006) and (Pennathur and Mital, 2003). Sung et. al. (2008) have described the importance of having personnel with the appropriate skills and how it can bring long term advantages. Therefore, training has become one of the key elements in improving work quality among organisations and has proven its efficiency in equipping staff members with the elementary knowledge and skills to perform jobs with a full understanding of the processes (Goulding et. al., 2012) and (Aguinis and Kraiger, 2009).

The approach taken in this research is to develop a method which can allow the learning of the lean enablers such as *5S* and *Standard Operating Procedure (SOP)*, by simulating the workstations described in section 4.3 and section 5.2. The development stages include:

a) exploring methods of training used within organisations and analysing the aspects of setting up and running a training session: examining the existing training methods, extracting the major elements relevant for the training program and adopting the best practices in the proposed method,
b) examining the implementation of the lean enablers in a workplace and how staff members of an organisation are trained: identifying the main aspects of *5S* and *Standard Operating Procedure (SOP)*,

c) investigating the limitations of the equipment used in the virtual reality (VR) system and developing a method which will allow for interaction and make decisions possible during a training simulation, and

d) generating the performance measures of a simulation run and being able to analyse them.

This chapter illustrates the proposed method by presenting its advantages, and how it can complement the existing training programmes in organisations. In the first part, the implementation of the proposed method will be outlined by describing the steps required to set up a training session. The second part will examine the contribution of the research in the existing training programmes mentioned in section 3.6. Then, a discussion of the results will follow by demonstrating the different benefits offered by the method developed in this research. Finally the limitations of the virtual reality (VR) training program will be mentioned.

6.2 Implementation steps of the proposed method

The storyboard in figure 6.1 illustrates the procedure of setting up a training session using the method developed in section 4.3 for the *5S training program* and section 5.2 for *the Standard Operating Procedure (SOP)* within the virtual reality (VR) system. This section is intended as a guide for step by step implementation of the proposed method in a training session for any lean enabler.

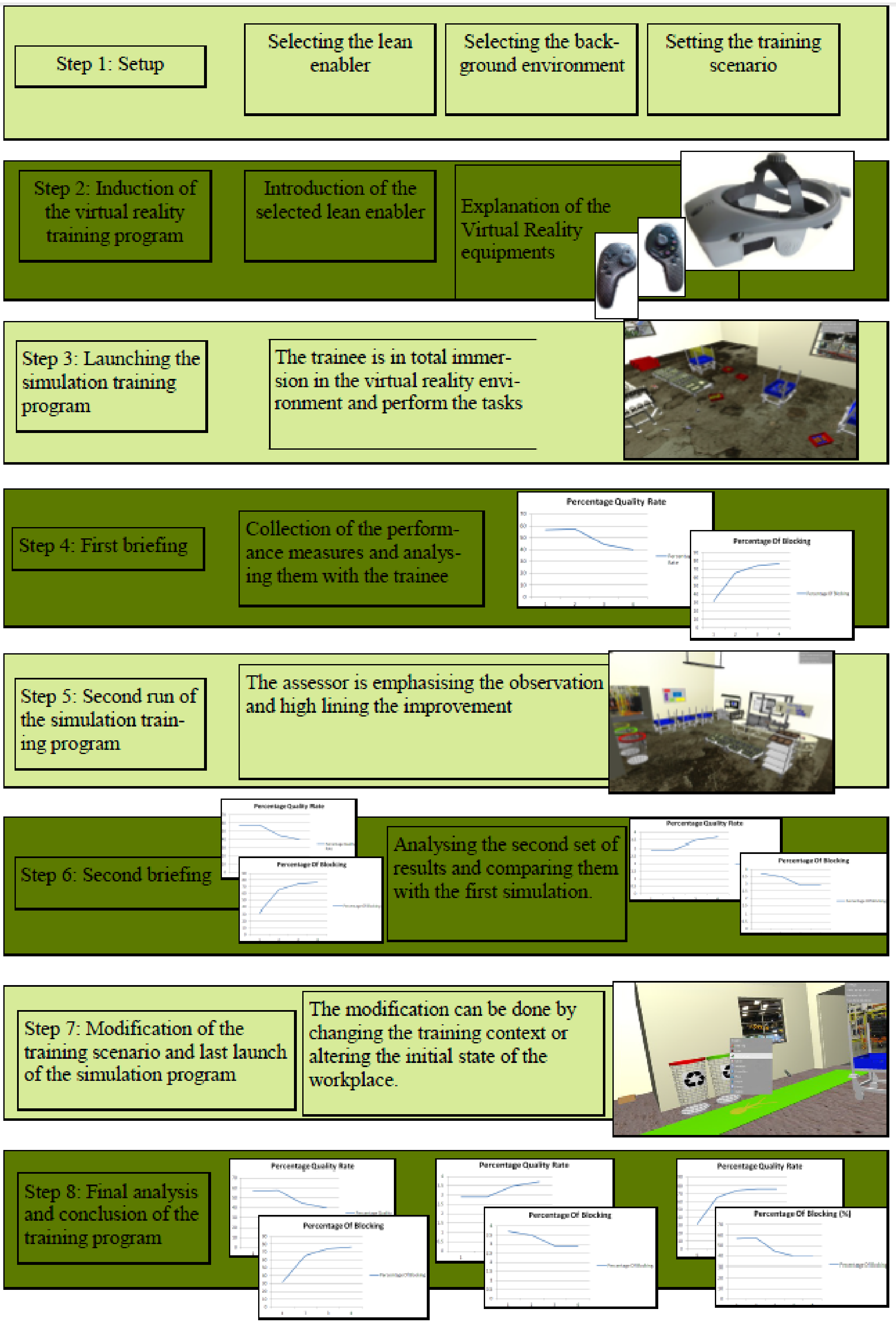


Figure 6.1: Generic structure to carry out any lean enabler training session within the VR system.

The figure 6.1 guides assessors/trainers through the stages necessary in order to set up and run the VR training program using the proposed method:

a) steps 1 and 2 – allow the setting up of the program by loading the training environment corresponding to either to the *5S* or *Standard Operating Procedure (SOP)* and the introduction to the trainee of the entire system including the use of the VR equipment and the interaction mechanism within the VR environment,
b) steps 3, 5 and 7 – describe the three consecutive runs as done in Caterpillar with the Simulated Working Environment (SWE) mentioned in section 6.2. They allow the monitoring of the trainee's learning curve,
c) step 4, 6 and 8 – illustrate the feedback session between each simulation run. The objective is for the trainee to get a better understanding of the exercise through analysing the output results i.e different performance measures collected.

Combining a practical session through the VR system and the feedback of the assessors/trainers allows a trainee to understand the outcomes and the impact of making wrong decisions during the simulation run i.e. VR training session. The point of a feedback session is to encourage practical learning by advising trainees during a simulation and enabling them to understand and correct themselves.

Between the first and second run, the objective is to demonstrate to the trainee the benefits behind the lean enablers and how they can improve work. In the third run, the training context gets changed; using the flexibilities offered by the virtual reality (VR) system, the assessors/trainers can change the initial setup of the virtual workplace in order to put the trainee into a different context than the one met in the first and second runs. This will allow for the evaluation of the level of understanding gained through observing the implementation of the lean enablers in a different situation and subsequent analysis of the results obtained at the end of the simulation. Consequently the assessors/trainers can rank the session according to the improvement made in the working environment between the first and the last simulation run.

6.3 The contribution of the research in the traditional training program

In section 3.6, several training programmes commonly used within large organisations have been mentioned, representing different approaches to set up and run a session. In this section, the aim is to look at those methods and describe how this research can contribute to the existing training programmes:

a) Training Within Industry

As defined in section 3.6.1, "Training Within Industry" is one of the training methods used by organisations to train staff members at work, which delivers training for managers/team leaders to gain the required skills with the aim of leading a workplace through providing the necessary guidance for personnel. According to Huntzinger (2006) one of the limitations of TWI is on the revision management. When a work process needs to be re-evaluated due to customer demand, not much support is provided to ensure that every single staff member has been updated with the new process.

This research offers a structure to conduct a training session using a virtual reality system. The method set in place offers a training platform where the simulated environment can be constructed /edited without major commitments, and which also has the capacity to update the work standard through the reference file: enabling trainers/assessors to update the training process as the work is evolving according to customers' requirements. Moreover, utilising VR system as a support allows the implementation of necessary changes while providing consistent training quality.

b) "On the job training"

The aim of the "on the job training" method used within organisations is to provide continuous training while being at work as mentioned in section 3.6.2. The concept stands on combining staff members of different skill levels in order to create an environment where the knowledge is transmitted while keeping the work flow. However as mentioned in section 3.5.2, Clark and Wall (1998) have illustrated a disadvantage of this training method which can affect directly the ongoing work due to the lack of experience of newcomers in the workplace. This aspect has been taken into account in this research when developing the training program. The objectives were to have a training environment which can provide to the trainee all the elements required to learn about the lean enablers but also to protect the ongoing work while being in a learning stage.

Moreover Almeida and Aterido (2011) have mentioned that "on the job training" is an approach where for the same concept, the content/details can vary according to the work ethic of an organisation – for example within a multinational organisation located in many countries, the same skills can be taught using the same approach but the outcomes may vary based on the work conditions and on how precisely the concepts are applied when completing the work. The VR training program elaborated in this research can be used as a tool to support the "on the job training" concept. It offers the trainee the possibility of having a concrete example of how to implement the taught skills. The issues mentioned by Almeida and Aterido (2011) can be solved, as the proposed method is capable of delivering the same training quality repetitively meaning that trainees throughout an entire department of an organisation can gain the same level of training.

c) Simulated Training Environment (SWE) within Caterpillar

Caterpillar has developed a "Simulated Working Environment (SWE)" with the objective of training a team of workers in order to improve work quality and reduce the wastes mentioned in section 2.4. The entire concept of the training stands on lean principles by implementing lean enablers such as *5S* and *Standard Operating Procedure (SOP)* (Despain et. al., 2003) and (Storey, 2002).

The "Simulated Working Environment (SWE)" is created by selecting a place within the organisation which serves only for training purposes. All elements of the shop floor are represented, from the content of the workplace to the varieties of work atmospheres that can exist. The training session is composed of several runs, aiming to teach the benefits of the lean principles by showing the different outcomes according to how the work has been completed. This research has been inspired by the method undertaken in Caterpillar and offers an environment which can suit any trainee through having an interactive training environment in which knowledge is applied in conjunction with the training settings. The application of a VR system permits the research to develop a training program which supports learning in a variety of ways such as:

i) clarifying the purpose of a training session to improve trainees' understanding of the *5S* and *Standard Operating Procedure (SOP)* through allowing the customisation of the simulated environment based on the trainee's professional background. Loading the suitable virtual environment sets up the working context to which the trainee will be exposed. It can enhance the purpose of implementing the lean enablers and encourages trainees to be alert throughout the simulation run by questioning each stage of the work procedure and seeking concrete answers (Burkolter et. al, 2010), and

ii) having the possibility for the assessors/trainers to follow the progression of a training session by observing the progression of the performance measures in real time.

Moreover the theoretical learning provided mainly during the induction that precedes a training session is combined with the practical experience through the virtual working environment and puts the proposed method in a position to deliver a training session where trainees can get the possibility of grasping the required knowledge and skills of the lean principles (Wan et. al., 2008).

d) Establishing/designing a training session

In section 3.6.3, several approaches have been mentioned for establishing/designing a training session. According to Neal (2013), a training session which is composed of written instructions and demonstration usually results in effective outcomes for trainees. In this research, Neal's (2013) findings have been taking into account by allowing a training program where instructions and demonstration (in the sense of practical experience) are present throughout a session. As described in section 6.2, but also during the development steps of the *5S* in section 4.3 and *Standard Operating Procedure (SOP)* in section 5.2, documents such as the storyboard illustrated in figure 4.2 and the "Standard Work Element Sheet (SWES)" illustrated in appendix 2.2 have been used to offer written support for trainees to understand the objective of the lean enabler and the desired results before starting a simulation run.

Finally, a workplace simulated by a VR system permits trainees to experience the problems and the pressure faced by industries while making crucial decisions and takes them through all the stages of the work process by providing effective instructions and enabling them to learn in a dynamic way through the process of making decisions (Wall and Ahmed, 2008).

6.4 Aspects of the training program developed

6.4.1 The main elements of a traditional training method implemented in the VR training program

Based on the literature review undertaken in section 3.4, table 6.1 lists the elements of a training programme considered important in organisations and illustrates their implementation within the VR training program.

Table 6.1: Adapting the VR training program with the main elements coming from the traditional training methods used within organisations.

Aspects of the traditional training programmes	Implementation of the main elements in the VR training program
Providing a theoretical explanation of the taught methods, rules and principles (Jenkins et al, 2010) and (Chauvin et al, 2009).	The theory of the lean enabler is taught through the training session. The induction provided by the assessor/trainer before running a simulation and the virtual environment providing a practical experience allow a trainee to progress in the simulation and to interact with the simulated working area in order to get the necessary explanation of the theoretical aspect of *5S* and *SOP* concepts.
Having a training programme which enables the provision of an identical quality of training regardless of the location (Kobak et al, 2003).	The equipment used in the virtual reality (VR) system is composed of three motion trackers, one receptor and two computers, which makes it a mobile system. The training program can be moved into another location to meet the trainees and provide the same training quality.
Enabling the assessor to observe and	Algorithms have been developed to generate

evaluate the performance measures in real time to provide feedback to trainees at the end of a training session **(**Kobak et al, 2003)	and display the performance measures in a "visualisation interface" with the aim of displaying in real time the progression of the output results during a simulation run. Additionally assessors/trainers can follow the simulation run by observing the trainee's behaviour while performing the exercise.
Being able to evaluate the knowledge gained by the trainee via the output results (Rowen et al, 2011)	The results are generated at each step of the training procedure either automatically or manually, e.g. sending a request from the "visualisation interface" to the VR training program to output the results. It gives assessors/trainers the option of consulting the results at any time during a simulation run.
Enabling an interactive learning platform which combines theoretical and practical skills (Jang et al, 2012).	The interaction within the VR training program is done through the VR equipment and the implementation of the *"decision-making*" tools. It allows users to visualise the properties of every modelling element, perform actions on them and manipulate them.

6.4.2 The flexibilities offered by the proposed method to design a training program

The efficiency of a training programme has been demonstrated by having a working environment which suits the professional background of the trainee and which offers a way to relate the taught concept in their workplace. The lean principles illustrated in section 2.3 have proven the programme's effectiveness in various domains regardless of the activities of an organisation (Saurin and Ferreira, 2009).

Also the features of the virtual reality (VR) system mentioned in section 3.4.2 offer flexibilities such as implementing new modelling elements – parts, work stations or an entire working environment. The equipment used is based on three tracking elements consisting of capturing the head and hand movement of the trainee during a simulation run, and one receptor which collects the data motion for the VR system. The composition of the equipment used for the virtual reality (VR) system also makes the training program physically flexible by having modules which can be portable without major settings such as the training environment created within Perkins (simulated working environment) aiming to train a team of workers on the concept of lean.

As defined in section 4.2 for the *5S* lean enabler and section 5.2 for the *Standard Operating Procedure (SOP)*, the training program requires the modelled work environment, which is composed of 3D modelling elements imported from a CAD model, to be loaded into the system. This procedure of setting up the simulation run allows the trainer to load any CAD model which will suit the scenario of the training session as well as the working atmosphere.

The research involved several experiments examining different ways of performing the training exercises. Those ways have been defined in section 4.2, for the *5S* and section 5.2 for the *SOP*, which combine different input parameters. The learning aspect comes mainly by allowing a trainee the possibility of analysing each situation and taking initiative based on the understanding of the implemented lean enabler. Through the total immersion of the trainee in the VR system and with the implementation of the "*decision-making*" tools, a constant thinking process is involved at each step of the training exercise. This technique of training allows theoretical knowledge to be combined with practical use.

Table 5.5 in section 5.2 displayed the results of the performance measures coming from the *SOP* training program. The outcome described an improvement of "people", "quality" and "velocity". The analysis of the experiments demonstrated that when a trainee follows the description of the standard work described in the Standard Work

Element Sheet (SWES) in appendix 2.2 and undertake the appropriate decisions and working methodology during the simulation run; the outcomes tend to get closer to the reference results, which symbolise the ideal performance measures.

The other important aspect of an effective training simulation program is the ability to provide all the necessary data in order to allow the assessor to analyse the simulation run and to provide constructive feedback to the trainee (Reinders et al, 2008). In this research, the results are provided to the trainers/assessors in several forms, such as:

- Collecting the performance measures at the end of each simulation run,
- displaying the results in real time while the trainee is performing in the VR training program, and
- Enabling the trainers/assessors to observe the trainee in the simulated work environment.

6.4.3 Development of the results display system

The results display system developed within the training simulation program permits the assessor to observe the progression of the trainee during the simulation run and analyse their skills in order to provide constructive feedback at the end of the session.

Two types of display have been implemented within the VR training program; they aim to assist the trainee during the simulation run in terms of necessary information such as visualising the properties of the modelling elements or the task duration.

In parallel with that another display has been developed which helps the assessor to observe the trainee's progression by displaying the performance measures in real time.

6.5 Discussion of results

The objective of the experiments undertaken in sections 4.3 and 5.2 was to evaluate the benefits of using the "*decision-making*" tools at each stage of the simulation run. The learning improvements brought about through the training program are demonstrated by analysing the results collected from the *5S* and *Standard Operation Procedure (SOP)* simulation.

6.5.1 Results obtained on the 5S training program

a) "% blocking", "%waiting" and "%working".

The results collected for *"%blocking", "%waiting"* and *"%working"* during the simulation runs demonstrate to a trainee the importance of the *5S* procedure in restructuring a workplace and making it efficient. The *"decision-making"* tools developed guide a trainee through a training session to implement the principles of the lean enabler and obtain high performance measures in a workplace – it makes the understanding and the learning of the principles more effective by indicating the benefits of applying the *5S* concept. Additionally the results display system developed make the analysis and the performance of actions easy in the virtual world, and workers as well as managers can develop the ability to understand the working structure and therefore organise the workplace using the *5S* concept in order to reduce the *"% waiting"* and *"%blocking"* and increase the *"% working"*.

b) “skills level”.

Producing quality work requires personnel to have the skills and knowledge of performing the job (Suer and Tummaluri, 2008) and also a working environment where the layout will be an advantage to improve quality (Inman et. al., 2003). The proposed method can identify the decisions made through trainee’s actions in organising the simulated workplace and therefore determine the level of understand in applying 5S. The outcomes in section 4.4 demonstrate an improvement of the *“% level of skill”* in the last experiment when the trainee uses the *“decision-making”* tools throughout the simulation run. It allows consulting each element that composes the workplace and then the trainee can decide whether or not it is relevant for the workplace. Using the *“decision-making”* tools force to observe and to analyse each set of the 5S, taking the appropriate decisions in order to reduce the wastes mentioned in section 2.4 and ultimately improve the understanding in 5S.

6.5.2 Results obtained on the Standard Operating Procedure (SOP) training program

As stated in section 5.2, step 10, the input parameters representing “*health and safety*”, “*hand motion*”, “*work sequence*” and “*tool handling*” symbolise the decisions made during the simulation runs, and consequently outputs have been collected as illustrated in table 5.5. The aim is to demonstrate the effects of the input parameters with regards to the performance measures during the *SOP* simulation runs.

a) People

The sets of results collected in section 5.2 demonstrate the influence of the standard work described in the “Standard Work Element Sheet (SWES)” illustrated in appendix

2.2 regarding the output for "*people"*. The training program can detect whether procedures related to "*health and safety*" have been implemented and generates the outcomes. It is elementary in a *Standard Operating Procedure (SOP)* that staff members have the awareness of "*health and Safety*" when implementing the concept. The virtual reality training program simulates this aspect and provides results reflecting the actions/decisions undertaken by a trainee. The observed results demonstrate that when the important aspects of *"health and safety"* are taken into account then a higher percentage of "*people"* is collected – it reflects the understanding of a trainee in the importance of health and safety elements and how to use them.

b) Quality

In the virtual reality (VR) training program, the output results for "*quality"* are linked with the *"work sequence"* and the *"hand movement"* performed during the production of an item as defined in section 5.2, step 7. Capturing data such as the hand movement realised by the trainee in a real world training environment can be challenging for the assessor. In this research the accuracy offered by the VR system allows for the development of an algorithm which enables the capturing of the hand motion at any time and with accuracy. Therefore the output results are derived according to the capture made by the system and allow the assessor to base the analysis on the training session. Being able to visualise the output at each stage and linking the effects of the results with what has been done during the simulation process can benefit the trainee tremendously. The percentage of *"quality"* improves as the trainee implements the standard work and ultimately demonstrates understanding of the concept.

c) Velocity

The aim of improving the output for "*people*" and "*quality*" also affects the time taken to complete a job and consequently improves "*velocity*". Indeed, following the procedure described by the *SOP* considerably reduces wastes in the production line and the trainee/user can observe the benefits of using the *"decision-making"* tools while manipulating the virtual object. Focus can be directed towards the assembly process, and on following the method described by the *SOP* as opposed to figuring out how to manipulate the virtual object and getting confused with the body movement in the VR system.

6.6 Limitations of the training program

A virtual reality (VR) system remains complex, especially in exploring the virtual environment using the VR equipment, for example the motion capture system. It is not obvious for every user and something trivial can become challenging – for example navigating in the virtual environment or manipulating 3D objects (Marcincin and Fecova, 2010). This can distract a trainee who can lose track of the initial objective and instead focus on manipulating an object in VR system. This research has looked at this aspect and enabled pre-set actions within the *"decision-making"* tools. As done in some video games, accessing the pre-set actions in a menu can be intuitive and keeps trainee focused in order to progress through the simulation run (Nijholt et. al., 2010).

Additionally the other limitation noticed in this research is at the physical level. The equipment that the VR system is composed of offers a certain degree of freedom to the trainee in order to perform movements which are captured by the system and converted into coordinates in the virtual environment. Nevertheless, the motion capture system selected in this research (a magnetic motion capture system, composed of three trackers and one receptor) has some limitation in terms of movement and manipulating 3D objects during a simulation run. Not having a *haptic device system* (consisting of sending a force feedback to the users which will enable a trainee to feel the virtual object) makes the interaction with 3D modelling challenging and involves building mechanisms within the VR system to overcome this aspect.

Finally when it comes to design a new work environment, implementing a new training environment by using 3D CAD models would require the reformatting of the model so it can suit the structure presented in section 4.3 and section 5.2. The design of the VR system can only follow standard structures listed in table 5.3 in order to implement a 3D model and cannot respond to something different.

Chapter 7: Conclusion

Training plays a major role in improving work within organisations by ensuring that the appropriate level of knowledge and skills are shared among personnel. It enables members of staff to gain the elementary abilities to perform jobs based on the work processes established to improve productivity.

This research has contributed to the existing training programmes used within organisations and has covered some of the problems faced. It provides a novel platform which combines a flexible environment to suit a trainee's needs in order to improve the teaching aspect, a practical experience and a results display system aiming to allow observation of the trainee's performance. Literature reviews were carried out about lean enablers and methods of training, and the implementation of a simulation program using a virtual reality (VR) system has been done by proposing a method which can improve the teaching:

a) The implementations of the *5S* and *Standard Operating Procedure (SOP)* as well as the training methods used in organisations have been defined in *chapter two* and *chapter three,*
b) The development of the simulated work environment under VR system for *5S* and *Standard Operating Procedure (SOP)* was mentioned in *chapter four* and *chapter five,* providing the structure established to design the modelling elements, integrate of the *"decision-making"* tools and develop the results display system.

c) The analysis of the outcomes was done in *chapter six* demonstrating the benefits of the developed method in guiding and supporting the trainee throughout sessions as well as enabling the implementation of the taught work methods.

Virtual reality (VR) is a system which is constantly under development and consequently further work can always be done in improving this type of training program. However, in comparison with existing methods of training, the method proposed in this research is flexible in that it can simulate complex working environments and be used to set up a training session personalised for the individual. Being portable by its very nature, it can be used in a potentially infinite variety of locations.

Chapter 8: Recommendations for Future Work

This research has proposed an approach consisting of adopting the lean training in a virtual environment with the aim of utilising the benefits of the virtual reality (VR) system in order to enhance the efficiency of a training session. The steps of the research have been elaborated in sections 4.3 and 5.2, for implementing *5S and Standard Operating Procedure (SOP)* as well as their respective results collected after running the experiments. The contribution of this thesis has been discussed in *chapter six* and can be considered as a basis for further improvement such as:

a) Establishing a method which can analyse the results of a training session and therefore propose an efficient work layout and working method in order to further improve productivity,
b) implementing a training program which can include more than one trainee at time in order to set up a simulated working environment for teamwork,
c) being able to implement other lean enablers using the same method developed in this research.
d) providing a pre –training session which can introduce all the features of the VR system e.g. how to use the controller and where to visualise the data
e) enabling analysing the moral/psychology of trainee in a simulation run

References

Abdullah, 2003, Lean manufacturing tools and techniques in the process industry with a focus on steel, PhD in Industrial Engineering

Abdulmalek and Rajgopal, 2007, Analysing the benefits of the lean manufacturing and value stream mapping via simulation: a process sector case study, *International Journal of Production economics*, Vol.107, N.1, pp.223-236

Aguinis and Kraiger, 2009, Benefits of Training and Development for individuals and Teams, Organizations, and Society, *Annual Review of Psychology*, Vol.60, pp.451-474

Alizon, Shooter and Simpson, 2009, Henry Ford and the Model T: lessons for produc plat forming and mass customisation, *International Journal of Design Studies*, Vol.30, N.5, pp.588-605

Almeida and Aterido, 2011, On-the-job training and rigidity of employment protection in the developing world: Evidence from differential enforcement, *International Journal of Labour Economics*, Vol.18, N.1, pp.389-394

Anand, Ward, Tatikonda and Schilling, 2009, Dynamic capabilities through continuous improvement infrastructure, *International Journal of Operation Management*, Vol.27, N.6, pp.444-461

Ariga, Kurosawa, Ohtake, Sasaki, Yamane, 2013, Roganization adjustment, job training and productivity: Evidence from Japanese automobile makers, *International Journal of the Japanese and International Economies*, Vol.27, pp.1-34

Bachmann, 2009, Supply-side effect of non-standard work options on elderly people employment in Japan, *International Journal of Equal Opportunities International*, Vol.28, N.8,pp.660-670

Bayo-Moriones, Bello-Pintado and Merino-Diaz de Cerio, 2009, 5S use in manufacturing plants: contextual factors and impact on operating performance, *International Journal of Quality & Reliability Management*, Vol.27, N.2, p217-230

Berkhof, Van Rijssen, Schellart, Anema and Van der Beek, 2011, Effective training strategies for teaching communication skills to physicians: An overview of systematic reviews, *International Journal of Patient Education and Counseling*, Vol.84, N.2, pp.152-162

Bertholey, Bourniquel, Rivery, Coudurier and Follea, 2009, Méthodes d'amélioration organisationnelle appliquées aux activités des établissements de transfusion sanguine (ETS): Lean manufacturing, VSM, 5S, *International Journal of Transfusion Clinique et Biologique*, Vol.16, N.2, pp.93-100

Blach, Landauer, Rosch and Simon, 1998, A highly flexible virtual reality system, *International Journal of Future Generation Computer System*, Vol.14, N.3-4, pp.167-178

Black, 2007, Design rules for implementing the Toyota Production System, *International Journal of Production Research*, Vol.45, N.45, pp3639-3664

Boyle, Scherrer-Rathje and Stuart, 2011, Learning to be lean: the influence of external information sources in lean improvements, *International Journal of Manufacturing Technology Management*, Vol.22, N.5, pp.587-603

Bright, Vine, Wilson, Masters and McGrath, 2012, Face validity, construct validity and training benefits of a virtual reality turp simulation, *International Journal of Surgery*, Vol.10, pp.163-166

Brunner, Korndorffer, Sierra, Massarweh, Dunne, Yau and Scott, 2004, Laparoscopic Virtual Reality Training: Are 30 Repetitions Enough?, International *Journal of Surgical Research*, Vol.122, pp.150-156.

Buche and Querrec, 2011, An expert system manipulating knowledge to help human learners into virtual environment, *International Journal of Expert System with Applications*, Vol.38, N.7, pp.8446-8457

Burkolter, Kluge, Sauer and Ritzmann, 2010, Comparative study of three training methods for enhancing process controls performance: Emphasis shift training, situation awareness training, and drill and practice, *International Journal of Computers in Human Behaviour*, Vol.26, pp.976-986

Buyurgan, Saygin and Kilic, 2004, Tool allocation in flexible manufacturing systems with tool alternatives, *International Journal on Robotics and Computer-Integrated manufacturing*, Vol. 20, pp. 341-349.

Cha, Han, Lee and Choi, 2012, A virtual reality based fire training simulator integrated with fire dynamics data, *International Journal of Fire Safety*, Vol.50, pp.12-24

Chauvin, Clostermann and Hoc, 2009, Impact of training programs on decision-making and situation awareness of trainee watch officers, *International Journal of Safety Science*, Vol.47, N.9, pp.1222-1231

Chen, Li and Shady, 2010, From value stream mapping toward a lean/sigma continuous improvement process: an industrial case study, *International Journal of Production Research*, Vol.48, N.4, pp.1069-1086

Cheng, Chen, Chen and Xiao, 2009, Research on 3D dynamic visualization simulation system of toxic gas diffusion based on virtual reality technology, *International Journal of Process Safety and Environmental Protection*, Vol.87, N.3, pp.175-183

Chincholkar and Herrmann, 2008, Estimating manufacturing cycle time and throughput in flow shops with process drift and inspection, *International Journal of Production Research*, Vol.26, N.24, pp.7057-7072

Chryssolouris, Mavrikios, Mourtzis, 2013, Manufacturing Systems: Skills and Competencies for the Future, Conference *on Manufacturing System 2013*, Vol.7, pp.17-24

Clarke and Wall, 1998, UK construction skills in the context of European developments, *International Journal of Construction Management and Economics*, Vol.16, N.5, pp.553-567

Clayton, Griffith, Price and Peters, 2002, Food handlers' beliefs and self-reported practices. *International Journal of Environmental Health Research*, Vol.12, N.1, pp.25-29

Cuatrecasas-Arbos, Fortuny-Santos and Vintro-Sanchez, 2011, The Operations-Time Chart: A graphical tool to evaluate the performance of production systems – from batch and queue to lean manufacturing, *International Journal of Computers and Industrial Engineering*, Vol.61, N.3, pp.663-675

Demeter and Matyusz, 2011, The impact of lean practices on inventory turnover, *International Journal of Production Economics*, Vol.133, N.2, pp.154-163

Deros, Saibani, Yunos, Rahman and Ghani, 2012, Evaluation of Training Effectiveness on Advanced Quality Management Practices, *International Journal of Procedia Social and Behavioral Sciences*, Vol.56, pp.67-73

Deros, Zohdi and Mohamad, 2012, A National Survey on dual training System Implementation in Malaysian Industry, *International Journal of Procedia Social and Behavioral Science*, Vol.60, pp.484-488

Despain, Ostrosky, Leinicke and Rexroad, 2003, Work Values at Caterpillar: A Process", *International Journal of Organizational Dynamics*, Vol.32, N.4, pp.405-414

Dessouky, Verma, Bailey and Rickel, 2001, A Methodology for Developing a Web-based Factory Simulator for Manufacturing Educated, *International Journal of IIE Transactions*, Vol.63, pp.195-205

Doolen and Hacker, 2005, A Review of Lean Assessment in Organizations: An Exploratory Study of Lean Practices by Electronics Manufacturers, *International Journal of Manufacturing Systems*, Vol.24, N.1, pp.55-67

Duflou, Kellens and Dewulf, 2011, Unit process impact assessment for discrete part manufacturing: A state of the art, *International Journal of Manufacturing Science and Technology*, Vol.4, N.2, pp.129-135

Eti, Ogaji and Probert, 2006, Strategic maintenance-management in Nigerian industries, International Journal of Applied Energy, vol.83, N.3, pp.221-227

Faggion and Tu, 2007, Standard Operating Procedure Approach for the Implementation of the Evidence-based Dentistry Concept in Dental Practice, *International Journal of Evidence Based Dental Practice*, Vol.7, N.3, pp.102-107

Faggion and Tu, Standard Operating Procedures Approach for the Implementation of the Evidence-based Dentistry Concept in Dental Practice, *International Journal of Evidence Based Dental Practice*, Vol.7,N.3,pp.102-107

Gadre, Cudney and Corns, 2011, Model Development of a Virtual Learning Environment to Enhance Lean Education, *International Journal of Procedia Computer Science*, Vol.6, p.100-105

Gamberi, Gamberini, Manzini and Regattieri, 2008, An analytical model to evaluating the implementation of a batch-production-oriented line, *International Journal of production*, Vol.111, N.2, pp.729-740

Gaoliang, Xu, Xin and Alipour, 2008, Precise manipulation approach to facilitate interactive modular fixture assembly design in a virtual environment, *International Journal of Assembly Automation*, Vol.28, N.3, pp.216-224

Gapp, Fisher and Kobayashi, 2008, Implementing 5S within a Japanese context: an integrated management system, *International Journal of Management Decision*, Vol.46, N.4, pp. 565-579

Garcia, Marchetta, Camargo, Morel and Forradellas, 2012, A framework for measuring logistics performance in the wine industry, International Journal of Production Economics, vol.135, n.1, pp.284-298

Gegenfurtner and Vauras, 2012, Age-related differences in the relation between motivation to learn and transfer of training in adult continuing education, *International Journal of Contemporary Educational Psychology*, Vol.37, pp.33-46

Gilgeous and Gilgeous, 1999, A framework for manufacturing excellence, *International Journal of Integrated Manufacturing Systems*, Vol.10, N.1, pp.33-44

Goulding, Nadim, Petridis and Alshawi, 2012, Construction industry offsite production: A virtual reality interactive training environment prototype, *International Journal of Advanced Engineering Informatics*, Vol.26, N.1, pp.103-116

Granerud and Rocha, 2011, Organisational learning and continuous improvement of health and safety in certified manufacturers, *International Journal of Safety Science*, Vol.49, N.7, pp.1030-1039

Gratiela, 2012, Study case: yellow tag vs quality management, *International Journal of Procedia Social and Behavioral Sciences*, Vol.62, pp.313-318

Graup and Wrona, 2006, The TWI Workbook: Essential Skills for Supervisors, Book published by Productivity Press in USA

Grounds, Radley, Lynch, Nagaraju and De Luca, 2008, Towards developing standard operating procedures for pre-clinical testing in the mdx mouse of Duchenne muscular dystrophy, *International Journal of Neurobiology of Disease*, Vol.31, N.1, pp. 1-19

Hale, 1995, Applied virtual reality research and applications at NASA/Marshall space flight center, *International Journal of Advances in Human Factors/ Ergonomics,* Vol.20, pp.523-528

Han and Park, 2002, Optimal buffer allocation of serial production lines with quality inspection machines, *International Journal of Computer and Industrial Engineering*, Vol.42, N.1, pp.75-89

Han, Ku, Kim, Jang, Park, Kim, Kim, Choi, Kim and Kim, 2008, Virtual reality prototype for measurement of expression characteristics in emotional situations, *International Journal of Computers in Biology and Medicine*, Vol.39, N.2, pp.173-179

Hasan, Ahamad and Mohamed, 2011, Skills and Competency in Construction Project Success: Learning Environment and Industry Application – The GAP, *The 2nd International Building Control Conference*, Vol.20, pp.291-297

Hedlund, Ateg, Andersson and Rosen, 2010, Assessing motivation for work environment improvements: Internal consistency, reliability and factorial structure, *International Journal of Safety Research*, Vol.41. N.2, pp. 145-151

Hernandez-Matias, Vizan, Perez-Garcia and Rios, 2008, An integrated modelling framework to support manufacturing system diagnosis for continuous improvement, *International Journal of Robotics and Computer-Integrated Manufacturing*, Vol.24, N.2, pp.187-199

Herron and Hicks, 2008, The transfer of selected lean manufacturing techniques from Japanese automotive manufacturing into general manufacturing (UK) through change agents, *International Journal of Robotics and Computer-Integrated Manufacturing*, Vol.24, N.24, pp.524-531

Hicks, 2007, Lean information management: Understanding and eliminating waste, *International Journal of Information Management*, Vol.27, N.4, pp.233-24

Hirano, 1996, 5S for Operators: 5 pillars of the visual workplace, Book published by Productivity Development Team.

Ho, 2010, Integrated lean TQM model for sustainable development, *International Journal of TQM model for sustainable development*, Vol.22, N.6, pp.583-593

Hogan, 2003, Lean initiatives and lean learning, *International Journal of Society of Manufacturing Engineers*, Vol.130, N.5, pp.115-118

Hon, 2005, Performance and Evaluation of Manufacturing Systems, International *Journal of CIRP Annals – Manufacturing Technology*, Vol.54, N.2, pp.139-154

Hsiung, Lai and Rau, 2011, The research on 3D Virtual Teaching of Color Calibration, *International Journal of Energy Procedia*, Vol.13, pp.9159-9164

Hsu and Chen, 2011, "Subordinated" perception of managers' transformational leadership style and satisfaction: a comparison of electronics manufacturing companies in Mainland China and Taiwan, *International Journal of Human Resource Management*, Vol.22, N.15, pp.3097-3108

Huntzinger, 2006, Why Standard Work is not Standard: Training Within Industry Provides and Answer, Vol.22, N.4

Imai, 1997, Gemba Kaizen: A Common-sense Low-cost Approach to Management, Book, edition McGraw-Hill, New York.

Inman, Blumemfeld, Huang and Li, 2003, Designing production systems for quality: Research opportunities from an automotive industry perspective, *International Journal of Production Research*, Vol.41, N.9, pp.1953-1971

Jahromi and Tavakkoli-Moghaddam, 2011, A novel 0-1 linear integer programming model for dynamic machine-tool selection and operation allocation in a flexible manufacturing system, *International Journal of Manufacturing System*, Vol.31, N.2, pp.224-231

Jang, Dixon, Tarbox, Granpeesheh, Kornack and de Nocker, 2012, Randomised trial of an elearning program for training family members of children with autism in the principles and procedures of applied behaviour analysis" *International Journal of Research in Autism Spectrum Disorders*, Vol.6, N.2 ,pp.852-856

Jenkins, Stanton, Salmon and Walker, 2010, A formative approach to developing synthetic environment fidelity requirements for decision-making training, *International Journal of Applied Ergonomics*, Vol.42, N.2, pp.159-169

Jenkins, Stanton, Salmon and Walker, 2011, A formative approach to developing synthetic environment fidelity requirements for decision-making training, *International Journal of Applied Ergonomics*, Vol.42, N.5, pp.757-769

Jensen and Friche, 2007, Effects of training to implement new tools and working methods to reduce knee load in floor layers, *International Journal of Applied Ergonomics*, Vol.38, N.5, pp.655-665

Karaman, Cobanoglu, Tunalioglu and Ova, 2012, Barriers and benefits of the implementation of food safety management systems among the Turkish dairy industry: A case study, *International Journal of Food Control*, Vol.25, N.2, pp.732-739

Kennedy and Widener, 2008, A control framework: Insights from evidence on lean accounting, *International Journal of Management Accounting Research*, Vol.19, N.4, pp301-323.

Ker, Reid, Dunkley and Steele, 2003, Attributes of trainers for postgraduate training in general surgery – A national consensus, *The Surgeon*, Vol.1, N.4, pp.215-220

Khalil, Stockton, David, Wright and Gillis, *2008*, Accelerating lean practice training using virtual reality, International Conference of Proceeding of MESM, pp.111-115

Klepper, Kenneth and Simons, 2005, Industry Shakeouts and Technological Change, *International Journal of Industrial Organization*, Vol.23, N.1-2, pp23-43

Kobak, Lipsitz and Feiger, 2003, Development of a standardized training program for the Hamilton Depression Scale using internet-based technologies: results from a pilot study, *International Journal of Psychiatric Research*, Vol. 37, N.6, pp.509-515

Kock, 2007, The team as a learning strategy – Three cases of team-based production in the Swedish manufacturing industry, *International Journal of Workplace Learning*, Vol.19, N.8, pp.480-496

Kuman and Budin, 2006, Prevention and management of product recalls in the processed food industry: A case study based on an exporter's perspective, *International Journal of Technovation*, Vol.26, N.5, pp.739-750

Laird, Naquin and Holton, 2003, New Perpectives in Orgnisational Learning, Performance, and Change: Approaches to Training and Development, *third Edition, Presus Books Group*, USA

Lee-Mortimer, 2008, A continuous lean journey: an electronic manufacturer's adopting of Kanban, *International Journal of Assembly Automation*, Vol.28, N.2, pp.103-112

Levesque, Ducharme, Caron, Hanson, Magnusson, Nolan and Nolan, 2010, A partnership approach to service needs assessment with family caregivers of an aging relative living at home: A qualitative analysis of the experiences of caregivers and practitioners" *International Journal of Nursing Studies*, Vol.47, N.7, pp.876-887

Liebisch and Gruhs, 2012, Linking theory and practice in Siemens' new training initiative – Using lean training to teach employees principles of lean manufacturing, *International Journal of Strategic Direction*, Vol.28, N.11, pp.12-13

Lin and Pearn, 2011, Group selection for production yield among k manufacturing lines, *International Journal of Statistical Planning and Inference*, Vol.141, N.4, pp.1510-1518

Lin and Yen, 2011, VoIP Digital Evidence Forensics Standard Operating Procedure, *International Journal of Research and Reviews in Computer Science*, Vol.2, N.1, pp.173-179

Liu and Zhang, 2008, A new man-machine interactive system for virtual assembly of large-scale products, *International Journal of Applied Mechanics and Materials*, Vol.10-12, pp.440-443

Liu and Zhang, 2010, Key technologies of a new man-machine interaction system, *Journal of Harbin Institute of Technology*, Vol.17, pp.190-192

Loven and Helender, 1997, Effect of operator competency on assessment of quality control in manufacturing, *International Journal of Industrial Ergonomics*, Vol.19, pp.307-316

Lu, Shpitalni and Gadh, 1999, Virtual and Augmented Reality Technologies for Product Realization, *CIRP Annals, Manufacturing Technology*, Vol. 48, N.2, pp.471-495

Macpherson and Jayawarna, 2007, Training approaches in manufacturing SMEs, Measuring the influence of ownership, structure and markets, *International Journal of Education and Training*, Vol.49, N.8, pp.698-719

Mager, Oomen, Morente, Knox, Kerr, Pezzella and Riegman, 2007, Standard operating procedure for the collection of fresh frozen samples, *European Journal of Cancer*, Vol.43, N.5, pp.828-834

Mahdjoub, Monticolo, Gomes and Sagot, 2010, A collaborative Design for Usability approach supported by Virtual Reality and a Multi-Agent System embedded in a PLM environment, *International Journal of Computer-Aided Design*, Vol.42, N.5, pp. 167-178

Maldonado, Henson, Caswell, Leos, Martinez, Aranda and Cadena, 2005, Cost-benefit analysis of HACCP implementation in the Mexican meat industry, *International Journal of Food Control*, Vol.16, N.4, pp.375-381

Mantzoukas, 2009, The research evidence published in high impact nursing journals between 200 and 2006: A quantitative content analysis, *International Journal of Nursing Studies*, Vol.46, N.4, pp.479-489

Marcincin and Fecova, 2010, The options of motion tracking in the virtual reality systems, *International Conference on Trends in the Development of Machinery and Associated Technology*.

Melton, 2005, The benefits of lean manufacturing, what lean thinking has to Offer the Process Industries, **International Journal of Chemical Engineering Research and Design**, vol.83, N.6, pp.662-673

Mirehei, 2011, Enhancing lean training for the office environment through simulation and gaming, *International Journal of Learning and intellectual Capital*, Vol.8, N.2, pp.206-221

Modell, 2005, Triangulation between case study and survey methods in management accounting research: As assessment of validity implications, *International Journal of Management Accounting Research*, Vol. 16, N.2, pp.231-254

Moreira, Goncalves, Laender and Fox, 2008, Automatic evaluation of digital libraries with 5SQual, *International Journal of Informetrics*, Vol.3, N.2, pp.102-123

Morge, Toczek and Chakroun, 2010, A training programme on managing science class interactions: Its impact on teachers' practises and on their pupils' achievement, *International Journal of Teaching and Teacher Education*, Vol.26, N.3, pp.415-426

Mujber, Szecsi and Hashmi, 2004, Virtual reality applications in manufacturing process simulation, *International Journal of Materials Processing Technology*, Vol.155-156, pp.1834-1838

Nastasi and Schensul, 2005, Contribution of qualitative research to the validity of intervention research, *International Journal of School Psychology*, Vol.43, N.3, pp.177-195

Neal, 2013, Comparative analysis of training delivery methods for new employees cleaning and sanitizing retail deli slicers: An exploratory study, *International Journal of Food Control*, Vol.29, pp.149-155

Nejjar, 2011, The quality process in a professional context: Software industry case, *International Journal of Information Science and Technology (CIST)*, pp.11

Nicholas, 1998, Competitive manufacturing management: continuous improvement, lean production, customer-focused quality, Management and Organisation series book.

Nieto-Montenegro, Brown and LaBorde, 2007, Development and assessment of pilot food safety educational materials and training strategies for Hispanic workers in the mushroom industry using the Health Action Model, *International Journal of Food Control*, Vol.19, pp.616-633

Nijholt, Reidsma and Poppe, 2010, Chapter 16 – Games and Entertainment in Ambient Intelligence Environments, *International Journal of Human-Centric Interface for Ambient Intelligence*, pp.393-413

Ohno, 2011, The optimal control of just-in-time based production and distribution systems and performance comparisons with optimized pull systems, *International Journal of Operational Research*, Vol.213, N.1, pp.124-133

Oppenheim, Murman and Secor, 2009, Lean thinking for Systems Engineering, *International Journal of Systems Engineering*, Vol.14, N.1, pp.29-55

Ozbayrak, Akgun and Turker, 2004, Activity-based cost estimation in a push/pull advanced manufacturing system, *International Journal of Production Economics*, Vol.87, N.1, pp.49-65

Packham, Rafiq, Borthwick and Denham, 2005, Interactive visualisation for decision support and evaluation of robustness- in theory and in practice, *International Journal of Advanced Engineering Informatics*, Vol.19, N.4, pp.263-280

Patnaik, Satpathy and Panigrahi, 2011, A comparative analysis of student's (boys) perception on training methods and techniques: A survey, *International Journal of Economy Research*, Vol.2, N.3, pp.7-12

Pennathur and Mital, 2003, Worker mobility and training in advanced manufacturing, *International Journal of Industrial Ergonomics*, Vol.32, N.6, pp.363-388

Peplies, Kottman, Ludwig and Glockner, 2008, A standard operating procedure for phylogenetic inference (SOPPI) using (rRNA) marker genes, *International Journal of Systematic and Applied Microbiology*, Vol.31, pp.251-257

Perez and Sanchez, 2000, Lean production and supplier relations: a survey of practices in the Aragonese, *International Journal of Technovation*, Vol.20, N.12, pp.665-676

Perrin, Perrin, Blauth, Apthorp, Duffy, Bonterre and Daniels, 2012, Factor analysis of global trends in twenty-first century leadership, *International Journal of Leadership and Organization Development*, Vol.33, N.2, pp.175-199

Pillet and Maire, 2008, How to sustain improvement at high level: Application in the field of statistical process control, *The TQM Journal*, Vol.20, N.6, pp.570-587

Pisuchpen, 2012, Integration of JIT flexible manufacturing, assembly and disassembly using a simulation approach, *International Journal of Assembly Automation*, Vol.32, N.1, pp.51-61

Raybourn, 2007, Applying simulation experience design methods to creating serious game-based adaptive training systems, *International Journal of Interacting with Computers*, Vol.19, N.2, pp.206-214

Rebsamen, Boucheix and Fayol, 2010, Quality control in the optical industry: From a work analysis of lens inspection to a training programme, an experimental case study, *International Journal of Applied Ergonomics*, Vol.41, N.1, pp.150-160

Reinders, Blankenstein, Marwijk, Schleypen, Schoonheim and Stalman, 2008, Development and feasibility of a patient feedback programme to improve consultation skills in general practice training, *International Journal of Patient Education and Counselling*, Vol.72,N.1, pp.12-19

Rivera and Chen, 2007, Measuring the impact of Lean tools on the cost-time investment of a product using cost-time profiles, *International Journal Robotics and Computer-Integrated Manufacturing*, Vol.23, N.6, pp.684-689

Rowen, Prata and Passano 2011, Evaluation of a traditional birth attendant training programme in Bangladesh, *International Journal of Midwifery*, Vol.27, N.2, pp.229-236

Roy, Souchoroukov and Shehab, 2008, Detailed cost estimating in the automotive industry: Data and information requirements, *International Journal of Production Economics*, Vol.133, N.2, pp.694-707

Sadasivan and Gramopadhye, 2009, Technology to support inspection training in the general aviation industry: Specification and design, *International Journal of Industrial Ergonomics*, Vol.39, N.4, pp.608-620

Salleh, Kasolang and Jaffar, 2012, Simulation of Integrated Total Quality Management (TQM) with Lean Manufacturing (LM) Practices in Forming Process Using Delmia Quest, *International Journal of Engineering Procedia*, Vol.41, pp.1702-1707

Saurin and Ferreira, 2009, The impacts of lean production on working conditions: A case study of harvester assembly line in Brazil, *International Journal of Industrial Ergonomics*, Vol.39, N.2, pp.403-412

Schmid, 2012, How to develop a Standard Operating Procedure for sorting unfixed cells, *International Journal of Methods*, Vol.57, pp.392-397

Schubert and Strobach, 2012, Video game experience and optimized executive control skills – On false positives and false negatives: Reply to Boot and Simons (2012*), International Journal of Acta Psychologica*, Vol.141, N.2, pp.278-280

Schwarstzman, Hsu, Law and Chung, 2011, Assessment of patient communication skills during OSCE: Examining effectiveness of a training program in minimizing inter-grade variability, *International Journal of Patient Education and Counselling*, Vol.83, N.3, pp.472-477

Servais, LaMorte, Agarwal, Moschetti, Mallipattu and Moulton, 2006, Teaching Surgical Decision-Making: An Interactive Web-Based Approach, *International Journal of Surgical Research*, Vol.134, N.1, pp.102-106

Shah and Ward, 2003, Lean manufacturing: context, practice bundles, and performance, *International Journal of Operations Management*, Vol.21, N.2, pp.129-149

Shang, Chung, Fry, Vezzadini and Colombo, 2009, How a process simulator and a rule-based system contribute to virtual reality applications for process safety, *International Journal of Computer Aided Chemical Engineering*, Vol.26, pp.435-439

Shiozawa, Hirt, Celebi, Baur, Weyrich and Lammerding-Kopell, 2010, Development and implementation of a technical and didactical training programme for student tutors in the dissection course, *International Journal of Annals of Anatomy*, Vol.192, N.6, pp.355-360

Si and Yang, 2012, Research of the Application of Virtual Reality in Green Construction, *International Journal of Advanced Materials Research*, Vol.462, pp.592-597

Simatupang, Sandroto and Lubis, 2012, Supply Chain coordination in a fashion firm, *International Journal of Supply Chain Management*, Vol.9, N.3, pp.256-268

Simons and Zokaei, 2005, Application of lean paradigm in red meat processing, British Food Journal, Vl107, N.4, pp.192-211

Smets, Abbing, Neerincx, Lindenberg and Van Oosterdorp, 2010, Game-based versus storyboard-based evaluation of crew support prototypes for long duration missions, *International Journal on Asta Autromautica*, Vol.66, pp.810-820.

Song, Sohn, Chung, Cho, Kim, Ahn, Chung, Shim, Kim and Yoshida, 2008, The development of standard operating procedures for the SDS of the ITER tritium plant, *International Journal of Fusion Engineering and Design*, Vol.83, N.10-12, pp. 1380-1383

Stark, Israel and Wohler, 2010, Towards hybrid modelling environments- Merging desktop- CAD and virtual reality- technologies, *International Journal of Manufacturing Technology*, Vol.59, N.1, pp.43-55

Storey, 2002, Education, training and development policies and practices in medium-sized companies in the UK: do they really influence firm performance?, International Journal of Management Science, Vol.30, pp.249-264.

Suarez-Barraza, 2009, Implementation of Lean-Kaizen in the human resource service process, *International Journal of Manufacturing Technology*, Vol.21, N.3, pp.388-410

Suer and Tummaluri, 2008, Multi-period operator assignment considering skills, learning and forgetting in labour-intensive cells, *International Journal of Production Research*, Vol.46, N.2, pp.469-493

Sung, Raddon and Ashton, 2008, The Business Benefits of Training in the Food and Drink Manufacturing Industry, Centre for Labour Market Studies, University of Leicester

Talaei-Khoei, Ray, Parameshwaran and Lewis, 2012, A framework for awareness maintenance, *International Journal of Network and Computer Applications,*Vol.35, N.1, pp.199-210

Tan, Lim, Platts and Koay, 2006, An intelligent decision support system for manufacturing technology investments, *International Journal of Production Economics*, Vol.104, N.1, pp.435-451

Tavil, 2010, A sample parent training programme: group training, *International Journal of Procedia Social and Behavioral Science*, Vol.9, pp. 1048-1054

Terry, 2011, Geographic limits to global labour market flexibility: The human resources paradox of the cruise industry, *International journal of Geoforum*, Vol.42, N.6, pp.660-670

Thiry, 2004, How can the benefits of PM training programs be improved?, *International Journal of Project Management*, Vol.22, N.1, pp.13-18

Thomson, Petty, Ramage and Moore, 2011, Qualitative research: Exploring the multiple perspective of osteopathy, *International Journal of Osteopathic Medicine*, Vol.14, pp.116-124.

Treville and Antonakis, 2006, Could lean production job design be intrinsically motivating? Contextual, configurational, and levels-of-analysis issues, *International Journal of Operations Management*, Vol.24, pp.99-123

Trika, Banerjeet and Kashyapt, 1997, Virtual reality interfaces for features-based computer-aided design systems, *International Journal of Computer-Aided Design*, Vol.29, N.8, pp.565-574

Upton, 1996, Mechanisms for building and sustaining operations improvement, *European Management Journal*, Vol.14, N.3, pp.215-218

Vaivio and Siren, 2010, Insights into method triangulation and "paradigms" in interpretive management accounting research, *International Journal of Management Accounting Research*, Vol.21, N.2, pp.130-141

Van Velzen, Volam, Brekelmans and White, 2011, Guided work-based learning: Sharing practical teaching knowledge with student teachers, *International Journal on Teaching and Teacher Education*, pp.1-11.

Wagner, 2009, Hands around the job [training within industry], *International Journal of Mechanical Engineering*, Vol.131, N.2, pp.28-31

Waldhausen, Avansino, Libby and Sawin, 2010, Application of lean methods improves surgical clinic experience, *International Journal Pediatric Surgery*, Vol.45, N.7, pp.1420-1425

Wall and Ahmed, 2008, Use of Simulation Game in Delivering Blended Lifelong Learning in the Construction Industry-Opportunities and Challenges, *International Journal of Computers and Education*, Vol.50, pp.1383-1393

Wan, Chan and Saygin, 2008, Simulation and Training for Lean Implementation Using Web-Based Technology, *International Journal of Service Operations and Informatics*, Vol.3, N.1, pp.1-14

Wang, Mohamed, Abourizk, Asce and Rawa, 2009, Flow Production of Pipe Spool Fabrication: Simulation to Support Implementation of Lean Technique, *International Journal of Construction Engineering and Management*, pp.1027-1038

Warwood and Knowles, 2004, An investigation into Japanese 5-S practice in UK industry, *The TQM Magazine*, Vol.16, N.5, pp.347-353

Westerman, 2006, What counts as "good" quantitative research and what can we say about when to use quantitative and/or qualitative methods?, *International Journal on New Ideas in Psychology*, Vol. 24, pp. 263-274.

Wickramasinghe and Wickramasinghe, 2011, Differences in Organisational Factors by Lean Duration, *International Journal of Operations Management Research*, Vol.4, N.3, pp.111-126

Woodman, Akehurst, Hardy and Beattie, 2010, Self-confidence and performance: A little sefl-doubt helps, *International Journal of Psychology of Sport and Exercise*, Vol.11, N.6, pp.467-470

Xu and Taylor, 2002, A novel virtual environment construction approach for manufacturing simulations, *European Journal of Mechanical and Environmental Engineering*, Vol.10-12, pp.440-443

Yang, Hong and Modi, 2011, Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms, *International Journal of Production Economics*, Vol.129, pp.251-261

Yoshikawa, Kalil, Weisner and Way, 2008, Mixing Qualitative and Quantitative Research in Developmental Science: Uses and Methodological Choices, *International Journal of Research in Mental Retardation*, Vol.35, pp.151-203

Yousri, Khan, Chakrabarti, Fernandes and Wahab, 2011, Lean thinking: Can it improve the outcome of fracture neck of femur patients in a district general hospital?, *International Journal of Care Injured*, Vol.42, N.11, pp.1234-1237

Yusoff and Salim, 2011, Investigating cognitive task difficulties and expert skills in e-learning storyboards using a cognitive task analysis technique, *International journal of Computer and Education*, Vol.58, N.1, pp.652-665

Bibliography

Abdulmalek and Rajgopal, 2006, Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study, *International Journal of Production Economics*, Vol.107, pp.223-236

Aggelogiannaki and Sarimveis, 2008, Design of a novel adaptive inventory control system based on the online identification of lead time, *International Journal of Production Economics*, Vol.114, N.2, pp.781-792

Aguado, Alvarez and Domingo, 2012, Model of efficient and sustainable improvements in a lean production system through process of environmental innovation, *International Journal of Cleaner Production*, pp.1-8

Ahmed, Hassan and Taha, 2005, TPM can go beyond maintenance: excerpt from a case implementation, International Journal of Quality in Maintenance Engineering, Vol.11, N.11, pp.19-42

Antony, Kumar and Madu, 2005, Six Sigma in small and medium-sized UK manufacturing enterprises: Some empirical observations, *International journal of Quality and Reliability management*, Vol.22, N.8, pp.860-874

Atanda, Podrasky-Mattia and Benton, 2005, Developing a data collection system, *International journal of Evaluation and Program Planning*, Vol.28, N.3, pp.335-339

Baker, Ryan, Wents, Woods and Woods, 2009, Using Virtual Worlds inEducation: Second Life as an Educational Tool, *International Journal of Teaching of Psychology*, Vol.36, N.1, pp.59-64

Bertrand and Fransoo, 2002, Operations management research methodologies using quantitative modeling, *International Journal of Operations Management Research*, Vol.22, N.2, pp.241-264

Bordnick, Traylor, Copp, Graap, Carter, Ferrer and Walton, 2008, Assessing reactivity to virtual reality alcohol based cues, *International Journal of Addictive Behaviour*, Vol.33, N.6, pp.743-756

Chalice, 2007, Improving healthcare using Toyota lean production methods: 46 steps for improvement, Book published by American Society for Quality, USA

Cheryan, Meltzoff and Kim, 2011, Classrooms matter: The design of virtual classrooms influences gender disparities in computer science classes, *International Journal of Computer & Education*, Vol.57, N.1-2, pp.217-220

Corominas, Pastor and Plans, 2008, Balancing assembly line skilled and unskilled workers, *International Journal of Management Science*, Vol.36, N.6, pp.1126-1132

Cristancho, Moussa and Dubrowski, 2011, A framework-based approach to designing simulation-augmented surgical education and training programs, *The American Journal of Surgery*, Vol.202, N.3, pp.344-351

David, Geyer, Ley, He, Clift, Kwan, Sansom and Jackson, 2007, Time dependent material flow analysis of iron and steel in the UK, Part 2. Scrap generation and recycling, *International Journal on Resources Conservation and Recycling*, Vol. 51, pp.118-140.

Domingo, Alvarez and Pena, 2007, Materials flow improvement in a lean assembly line: a case study, *International Journal of Assembly Automation*, Vol.27, N.2, pp.141-147

Gaoliang, Gongdon, Wenjian and Haiquan, 2010, A desktop virtual reality-based interactive modular fixture configuration design system, *International Journal of Computer-Aided Design*, Vol. 42, N.5, pp.432-444

Gautam and Singh, 2010, Lean product development: Maximizing the customer perceived value through design change (redesign*), International Journal of Production Economics*, Vol.114, N.1, pp.313-332

Gong, 1998, An automated flow line control system design, *International Journal of Computer Integrated Manufacturing Systems*, Vol.11, N.3, pp.207-215

Gungor, 2011, The relationship between reward management system and employee performance with the mediating role of motivation: A quantitative study on global banks, *International Journal of Procedia, Social and Behabvioral Science*, Vol. 24, pp.1510-1520

Guttentag, 2010, Virtual Reality: Applications and implementations for tourism, *International Journal of Tourism Management*, Vol.31, N.5 pp.637-651.

Hamzadayi and Yildiz, 2011, A genetic algorithm based approach for simultaneously balancing and sequencing of mixed-model U-lines with parallel workstations and zoning constraints, *International Journal of Computers and Industrial Engineering*, Vol.62, N.1, pp.206-215

Hedlund, Ateg, Andersson and Rosen, 2010, Assessing motivation for work environment improvements: Internal consistency, reliability and factorial structure, *International Journal of Safety Research,* Vol.41, pp.145-151

Holtzclaw, 2009, Reading and interpreting a quantitative research study, *International Journal on Perioperative Nursing Clinics*, Vol.4, N.3, pp: 201-215

Hsieh and Young, 2010, Motion constraint design and implementation for a multi-functional virtual manipulation system, *International Journal of Mechatronics*, Vol.20, N.3, pp. 346-354.

Hua Tan and Rae, 2007, Lean Flexible Firm: Strategy for Managing Contractual Workers, *International conference on manufacturing research*, pp.143-147

Inoue, Ishii, Igarashi, Takagi, Muneta and Imaoka, 2006, Conveyer Belt Model to Analyze Cycle Time Conditions, *IEEE International Symposium on Semiconductor Manufacturing Conference Proceedings*, pp.74-77

Johnson and Diwakaran, 2011, An educational exercise examining the role of the model attributes on the creation and alteration of CAD models, *International Journal of Computers and Education*, Vol.57, N.2, pp.1749-1761

Kabouridis and Link, 2001, Quality assessment of continuing education short courses, *International Journal of Quality Assurance in Education*, Vol.9, N.2, pp.103-109

Kealey, Protheroe, MacDonald and Vulpe, 2005, Re-examining the role of training in contributing to international project success: A literature review and an outline of a new model training program, *International Journal of Intercultural Relations*, Vol.29, N.3,pp.289-316

Khalifa, Bogorad, Gibson, Peifer and Nussbaum, 2006, Virtual Reality in Ophthalmology Training, *International Journal of Diagnostic and Surgical Techniques*, Vol.51, N.3, pp. 259-273

Konishi, 2010, A tuning strategy to avoid blocking and starving in a buffered production line, *European Journal of Operational Research*, Vol. 200, N.2, pp.616-620.

Kumar, Sudhahar and Dickson, 2007, Performance analysis of 5S teams using quality circle financial accounting system, The TQM Magazine, Vol.19, N.5, pp.483-496

Linou and Kontogiannis, 2004, The effect of Training Systemic Information on the Retention of Fault-Finding Skills in Manufacturing Industries, *International Journal of Human Factors and Ergonomics in Manufacturing*, Vol.14, N.2, pp.197-217

Luo, Liberatore, Nydick, Chung and Sloane, 2004, Impact of process change on customer perception of waiting time: a field study, *International Journal of Management Science*, Vol.32, pp.77-83

Mentzer and Kahn, 1995, Framework of logistics research, *International Journal of business logistics*, Vol.6, N.1, pp. 231-250

Mikkelsen and Davidson, 2010, Inside the iPod, outside the classroom, *International Journal of Reference Service Review*, Vol. 39, N.1, pp-66-80

Mir, Gehl, Sersa, Collins, Garbay, Billard, Geertsen, Rudolf, O'Sullivan and Marty, 2006, Standard operating procedures of the electron chemotherapy: Instructions for the use of bleomycin or cisplatin administered either systemically or locally and electric pulses delivered by the Cleniporator by means of invasive or non-invasive electrodes, *European Journal of Cancer Supplements*, Vol.4, N.11, pp.14-25

Mo, 2009, The role of lean in the application of information technology to manufacturing, *International Journal of Computers in Industry*, Vol.60, N.4, pp.266-276

Nearchou, 2010, Maximizing production rate and workload smoothing in assembly lines using particle swarm optimisation, *International Journal of Production Economics*, Vol. 129, pp.242-250

Olaniyan and Ojo, 2008, Staff training and development: A vital tool for organisational effectiveness, *European Journal of Scientific research*, Vol.24, N.3, pp.326-331

Oppenheim, Murman and Secor, 2011, Lean enablers for System Engineering, *International Journal of System Engineering*, Vol.14, N.1, pp.29-55

Osterlund and Lawrence, 2011, Virtual reality: Avatars in human spaceflight training, Conference Paper presented during the 61st IAC (Prague).

Pangarkar and Wu, 2012, Industry globalization and the performance of emerging market firms: Evidence from China, *International Journal of Business Review*, Vol.21, N.2, pp.196-209

Pollitt, 2006, Culture change makes Crusader fit for the future, *International Journal of Human Resource Management International Digest*, Vol.14, N.2, pp.11-14.

Pranckevicius, Diaz and Gitlow, 2008, A lean six sigma case study: an application of the "5S" techniques, International Journal of Advances in Management Research, Vol.5, N.1, pp.63-79

Remus, 2007, Critical success factors for implementing enterprise portals- a comparison with ERP implementations, *International Journal of Business Process Management*, Vol. 13, N.4, pp. 538-552

Rigas, Konstandinidou, Centola and Reggio, 2003, Safety analysis and risk assessment in a new pesticide production line, *International Journal of Loss Prevention in The Process Industries*, Vol.16, N.2, pp.103-109

Rodrigues, Patel, Gopalakrishna, Shetty and Rao, 2010, Affect of Production Cycle time in Manufacturing Supply Chain Management: A System Dynamics Approach, *International Conference on Management of Innovation and Technology (ICMIT 2010)*, pp.146-150

Schmitt, Mengele, Schueren, Sweep, Foekens, Brunner, Laabs, Malik and Harbeck, 2006, European Organisation for Research and Treatment of Cancer (EORTC) Pathobiology Group standard operating procedure for the preparation of human tumour tissue extracts suited for the quantitative analysis of tissue-associated biomarkers, *European Journal of Cancer*, Vol.43, N.5, pp.835-844

Schmitz and Wiese, 2006, New perspectives for the evaluation of training sessions in self-regulated learning: Time-series analyses of diary data, *International Journal of Contemporary Educational Psychology*, Vol.31, N.1, pp.64-96

Schweitzer and Aurich, 2010, Continuous improvement of industrial product-service systems, *International Journal of Manufacturing Science and Technology*, Vol.3, N.2, pp.158-164

Scott, Wilcock and Kanetkar, 2009, A survey of structured continuous improvement programs in the Canadian food sector, *International Journal of Food Control*, Vol.20, N.3, pp.209-217

Stone, 2001, Virtual reality for interactive training: an industrial practitioner's viewpoint, *International Journal on Human Computer Studies*, Vol. 55, pp. 699-711.

Thurab-Nkhosi, 2009, Quality management in course development and delivery at the University of the West Indies Distance Education Centre, *International Journal of quality Assurance in Education*, Vol. 17, N.3, pp. 264-280

Upton and Kim, 1998, Alternative methods of learning and process improvement in manufacturing, *International Journal of Operations Management*, Vol.16, N.1, pp.1-20

Wang and Wang, 2007, A simulated model for cycle time reduction by acquiring optimal lot size in semiconductor manufacturing, *International Journal of Advanced Manufacturing Technology*, Vol.34, N.9-10, pp.1008-1015

Weniger and Irle, 2008, Allocentric memory impaired and egocentric memory intact as assessed by virtual reality in recent-onset schizophrenia, *International Journal of Schizophrenia Research*, Vol.101, N.1-3, pp.201-209

Wilson, King and Hodgson, 2004, Scheduling non-similar groups on a flow line: multiple group setups, *International Journal of Robotics and Computer-integrated Manufacturing*, Vol.20, N.6, pp: 505-515

Yamamoto, Abu Qudeiri and Marui, 2007, Definition of FTL with bypass lines and its simulator for buffer size decision, *International Journal of Production Economics*, pp-18-25

Yang and Shen, 2011, The dynamic transfer batch size decision for thin film transistor-liquid crystal display array manufacturing by artificial neural-network, *International Journal on Computer and Industrial Engineering*, Vol.60, pp.769-776

Zaeh and Mueller, 2007, A modelling approach for evaluating capacity flexibilities in uncertain markets, *International Journal of Flexible Manufacturing Systems*, Vol.19, N.3, pp.151-172

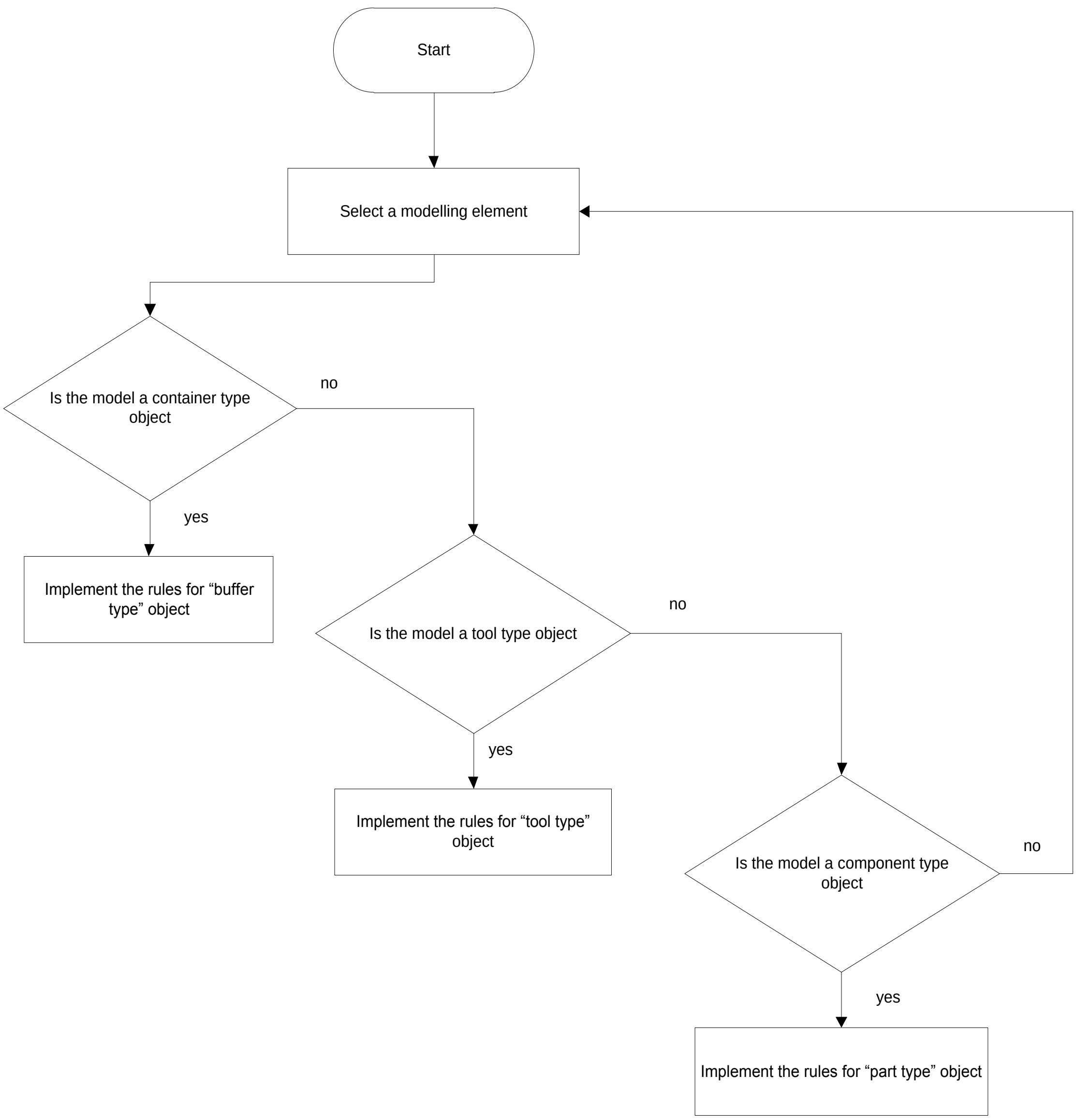
Appendix 1 – 5S training program.

5S Checklist - Workplace Evaluation	Evaluation Rank	
	Number of problems	**Score**
	5 or more	0
	3 to 4	1
	2	2
	1	3
	None	4

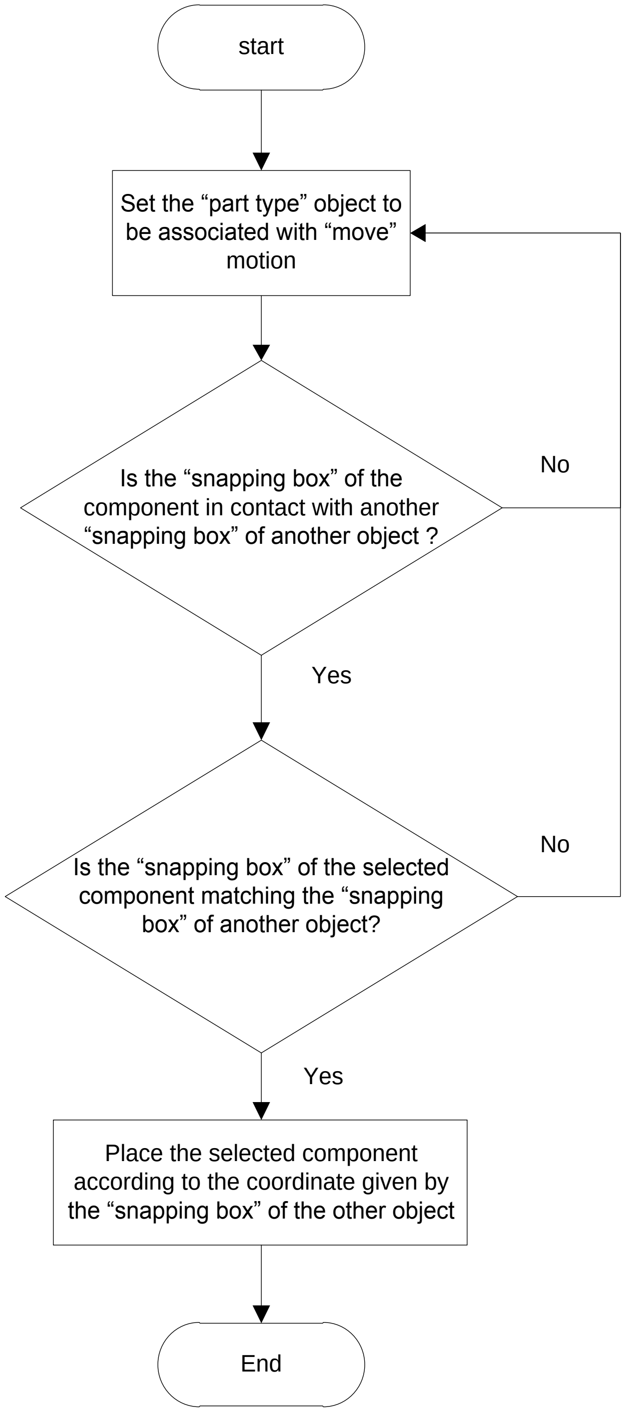
		Score		
Category	Items	1	2	3
Sort	**Distinguish between what is needed and not needed**			
	Unneeded equipment, tools, furniture, etc.	0	2	4
	Unneeded items are on walls, bulletin boards, etc.	0	4	4
	Items that are present in aisle ways, stairways, corners, etc..	0	2	3
	Red tag the unneeded inventory, supplies, parts, or materials are present	0	2	4
	Safety hazards (water, oil, chemicals, machines) exist	0	1	4
Simplify	**A place for everything and everything in place**			
	Correct places for items are obvious	1	3	4
		N/A	N/A	N/A
	Are things put away after use?			
	Aisle ways, workstations, equipment locations are not indicated	0	3	4
	Items are not put away immediately after use	N/A	N/A	N/A
	Height and quality limits are not obvious	N/A	N/A	N/A
Sweep	**Cleaning and booking for ways to keep it clean and organised**			
	Floors, walls, stairs and surfaces are not free of dirt, oil and grease	0	4	4
	Equipment is kept clean and free of dirt, oil and grease	0	4	4
	Cleaning materials are easily accessible	0	4	4

	Lines, labels, signs, etc. are dirty and/or broken	N/A	N/A	N/A
	Other cleaning problems (of any kind) are present	N/A	N/A	N/A
Standardize	**Maintain and monitor the first three categories**			
	Necessary information is available	0	3	4
	Not all standards are known or clearly visible	0	2	4
	Checklists do not exist for all cleaning and maintenance jobs	N/A	N/A	N/A
	Not all quantities and limits are easily recognizable	N/A	N/A	N/A
	How many items cannot be located in 30 seconds?	0	2	4
Sustain	**Stick to the rules**			
	How many workers have not had 5S training?	N/A	N/A	N/A
	Are personal belongings put away?	N/A	N/A	N/A
	How many times are personal belongings not neatly stored?	N/A	N/A	N/A
	Number of times job aids are not available or up to date.	N/A	N/A	N/A
	Number of times that daily 5S inspections were carried out last week.	N/A	N/A	N/A

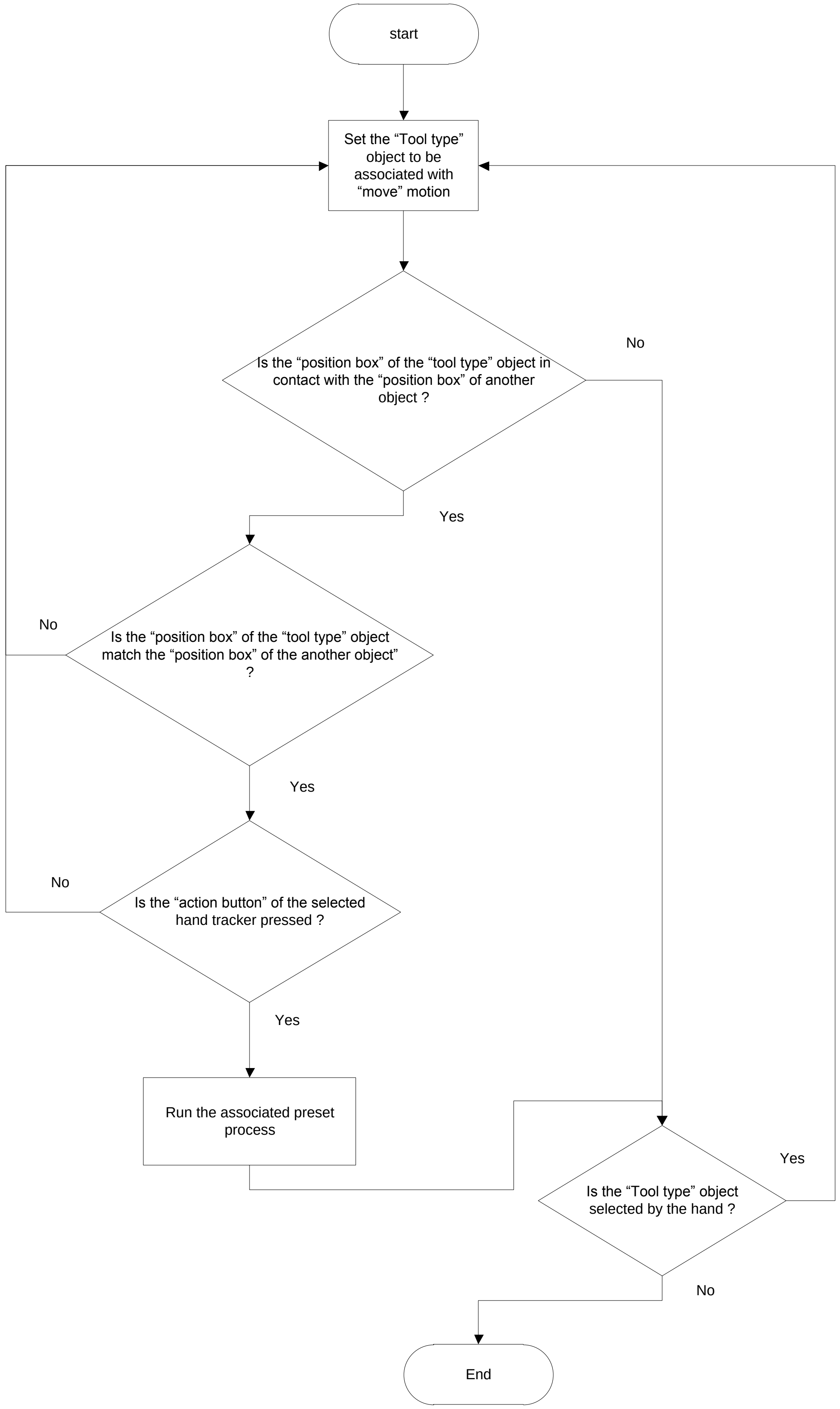
Appendix 1.1: Checklist for 5S lean enabler.



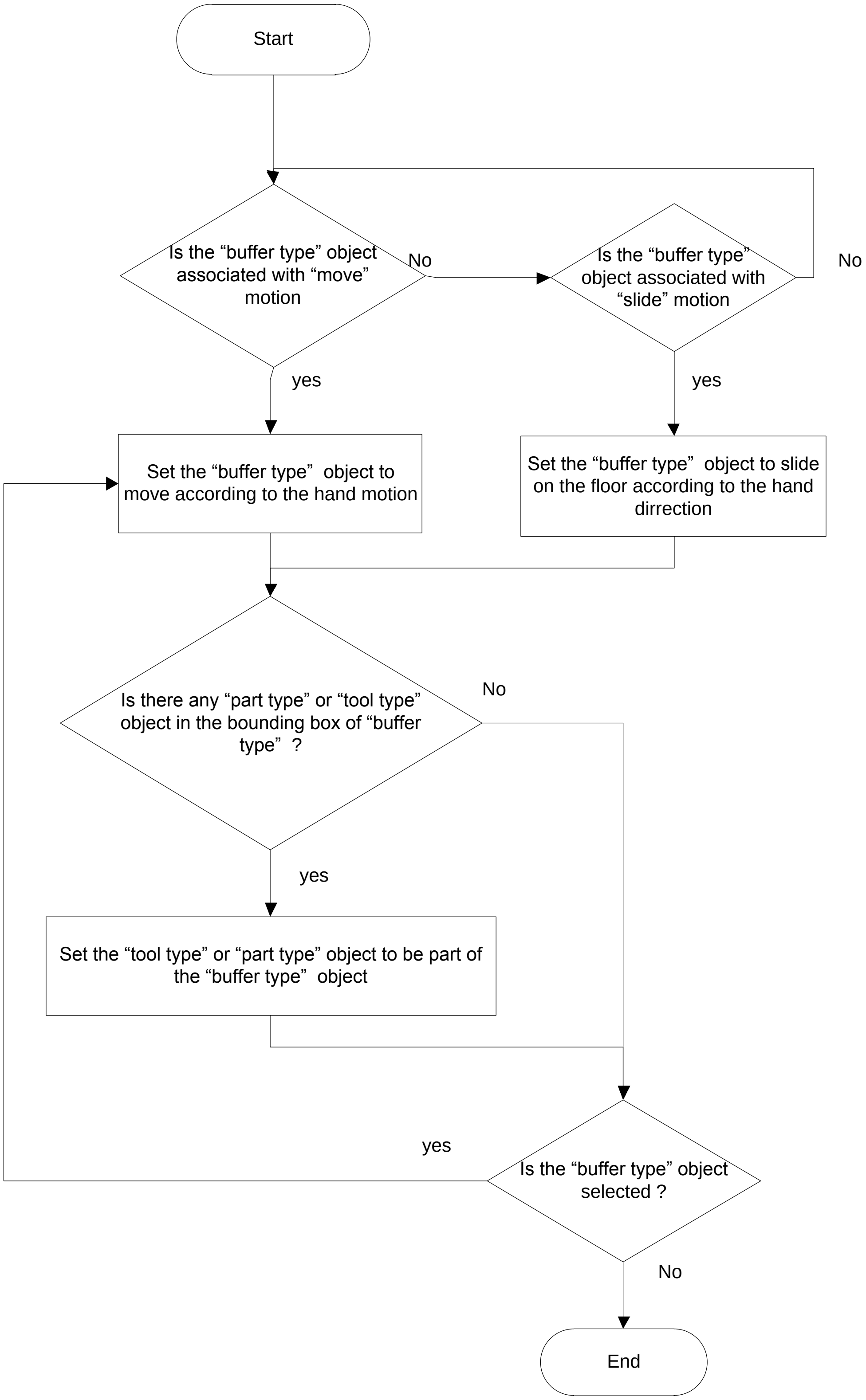
Appendix 1.2: General algorithm of the object development within the 5S training program.



Appendix 1.3: Algorithm of part type object developed within the 5S training program.



Appendix 1.4: Algorithm of tool type object within the 5S training program.



Appendix 1.5: Algorithm of a buffer type object.

Appendix 1.6: Results of the 5S collected during the first simulation run.

Sort: At the beginning of the simulation; investigating the working area	
Date/Time	06/11/2011 14:06
Simulation Time (mins)	0.1466174
% Blocking	45.2
% Waiting	38.6
% Working	16.2
% Skills level	15
Sort: red tag the unnecessary items in the working area	
Date/Time	06/11/2011 14:06
Simulation Time (mins)	2.2700504
% Blocking	44.3
% Waiting	33.4
% Working	22.3
% Skills level	17.9
Sort: setting of the shadow board for tools	
Date/Time	06/11/2011 14:08
Simulation Time (mins)	4.6695334
% Blocking	38.3
% Waiting	29.4
% Working	32.3
% Skills level	18.3
Simplifying: reorganisation of the working are with the objective of reducing the excessive motion	
Date/Time	06/11/2011 14:12
Simulation Time (mins)	8.5161504
% Blocking	35.7
% Waiting	25.7
% Working	38.6

% Skills level	23.6
Simplifying: setting recycling bins	
Date/Time	06/11/2011 14:20
Simulation Time (mins)	10.460683
% Blocking	33.6
% Waiting	27.6
% Working	38.8
% Skills level	35.4
Sweep: Cleaning the all floor with the use of the right decision making	
Date/Time	06/11/2011 16:30
Simulation Time (mins)	11.7112004
% Blocking	30.6
% Waiting	26.7
% Working	42.7
% Skills level	40.5
Standardisation stage; marking the floor in order to ensure the free path to the staff member	
Date/Time	06/11/2011 16:41
Simulation Time (mins)	12.9205674
% Blocking	28.9
% Waiting	25.3
% Working	45.8
% Skills level	41.3

Appendix 1.7: Results of the 5S collected during the second simulation run.

Sort: At the beginning of the simulation; investigating the working area	
Date/Time	06/11/2011 14:06
Simulation Time (mins)	0.1466174
% Blocking	35.4
% Waiting	34.2
% Working	30.4
% Skills level	17.9
Sort: red tag the unnecessary items in the working area	
Date/Time	06/11/2011 14:06
Simulation Time (mins)	2.2700504
% Blocking	33.4
% Waiting	27.5
% Working	39.1
% Skills level	23.4
Sort: setting of the shadow board for tools	
Date/Time	06/11/2011 14:08
Simulation Time (mins)	4.6695334
% Blocking	32.4
% Waiting	26.4
% Working	41.2
% Skills level	26.3
Simplifying: reorganisation of the working area is with the objective of reducing the excessive motion	
Date/Time	06/11/2011 14:12
Simulation Time (mins)	8.5161504
% Blocking	30.4
% Waiting	26.4
% Working	43.2

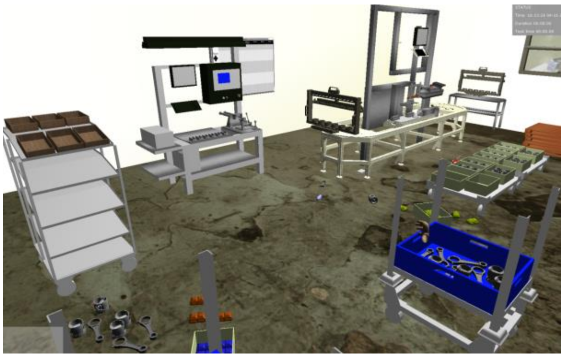
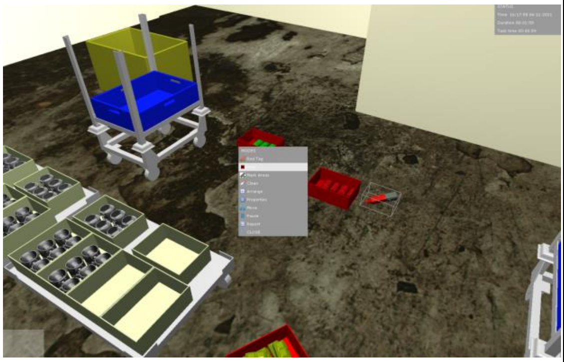
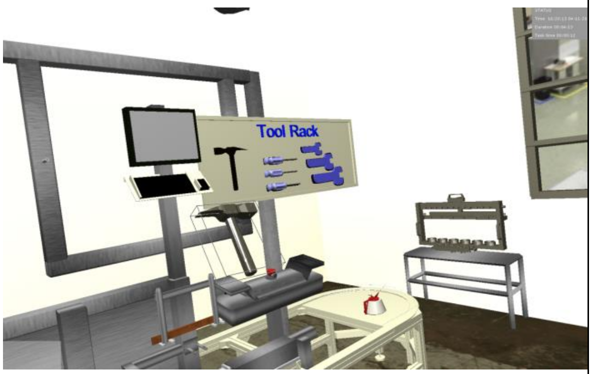
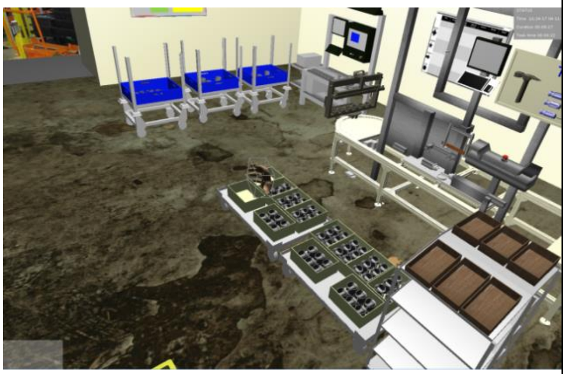
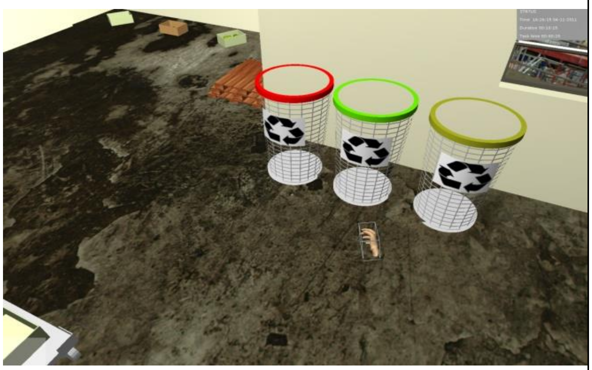
% Skills level	48.6
Simplifying: setting recycling bins	
Date/Time	06/11/2011 14:20
Simulation Time (mins)	10.460683
% Blocking	25.6
% Waiting	23.4
% Working	51
% Skills level	63.4
Sweep: Cleaning the all floor with the use of the right decision making	
Date/Time	06/11/2011 16:30
Simulation Time (mins)	11.7112004
% Blocking	23.4
% Waiting	16.7
% Working	59.9
% Skills level	75.4
Standardisation stage; marking the floor in order to ensure the free path to the staff member	
Date/Time	06/11/2011 16:41
Simulation Time (mins)	12.9205674
% Blocking	18.6
% Waiting	16.4
% Working	65
% Skills level	75.6

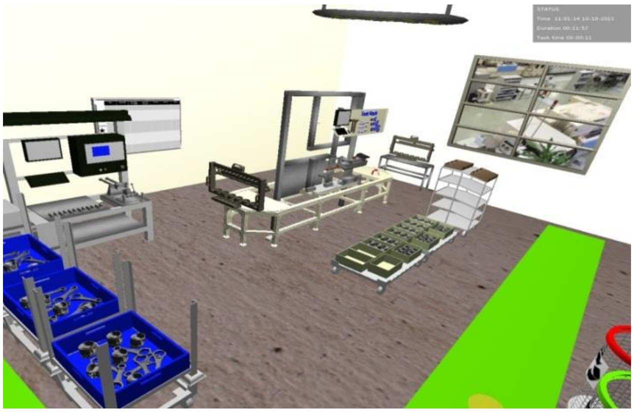
Appendix 1.8: Results of the 5S collected during the third simulation run.

Sort: At the beginning of the simulation; investigating the working area	
Date/Time	08/11/2011 10:20
Simulation Time (mins)	0.1466174
% Blocking	30.6
% Waiting	29.2
% Working	40.2
% Skills level	26.4
Sort: red tag the unnecessary items in the working area	
Date/Time	08/11/2011 10:20
Simulation Time (mins)	2.2700504
% Blocking	27.6
% Waiting	25.7
% Working	46.7
% Skills level	27.5
Sort: setting of the shadow board for tools	
Date/Time	08/11/2011 10:22
Simulation Time (mins)	4.6695334
% Blocking	25.12
% Waiting	23.6
% Working	51.28
% Skills level	36.4
Simplifying: reorganisation of the working area is with the objective of reducing the excessive motion	
Date/Time	08/11/2011 10:26
Simulation Time (mins)	8.5161504
% Blocking	21.3
% Waiting	15.6
% Working	63.1

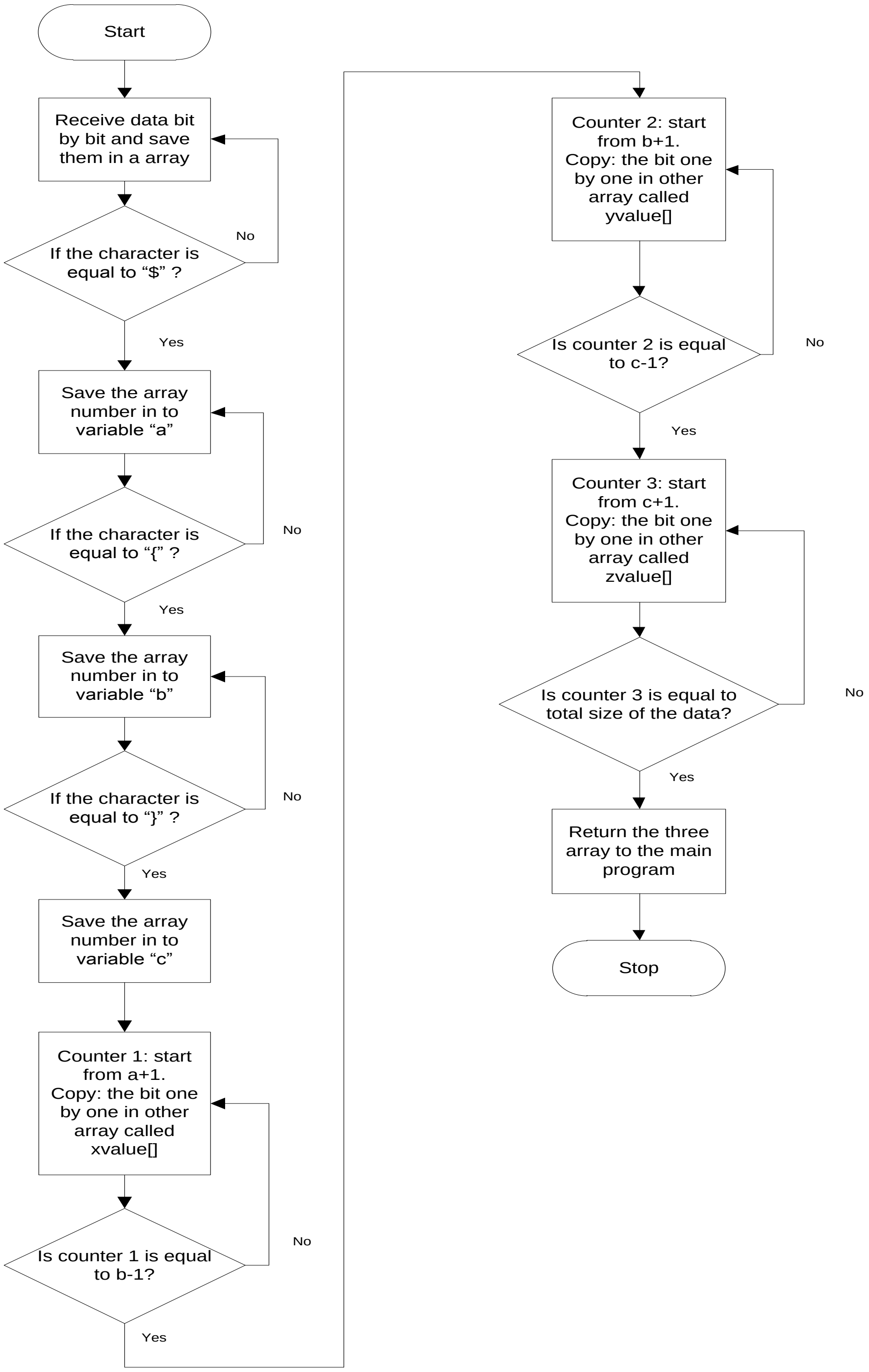
% Skills level	56.7
Simplifying: setting recycling bins	
Date/Time	08/11/2011 10:34
Simulation Time (mins)	10.460683
% Blocking	13.6
% Waiting	7.36
% Working	79.04
% Skills level	63.4
Sweep: Cleaning the all floor with the use of the right decision making	
Date/Time	08/11/2011 16:44
Simulation Time (mins)	11.7112004
% Blocking	15.3
% Waiting	5.6
% Working	79.1
% Skills level	75.4
Standardisation stage; marking the floor in order to ensure the free path to the staff member	
Date/Time	08/11/2011 16:55
Simulation Time (mins)	12.9205674
% Blocking	3.6
% Waiting	1.4
% Working	95
% Skills level	92.3

Appendix 1.9: Simulation runs of the 5S training program within the virtual reality system.

<table>
<tr><td colspan="2">Sorting</td></tr>
<tr><td>Analysing the workstation</td><td>Red tagging the unused items</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Simplifying</td></tr>
<tr><td>Use of a shadow board for tools</td><td>Organising the layout</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Sweeping</td></tr>
<tr><td>Using the recycling bins</td><td>Cleaning each part of the workstation</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Standardising</td></tr>
<tr><td colspan="2">Setting instructions and marking the floor in order to maintain the improvement</td></tr>
</table>

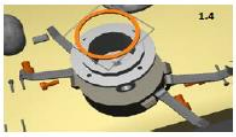
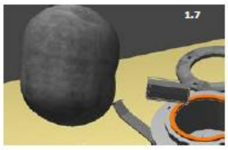

STATUS

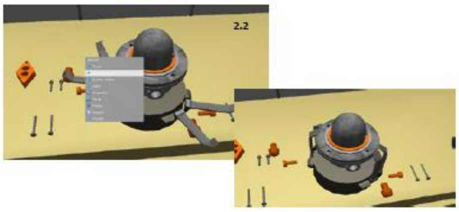
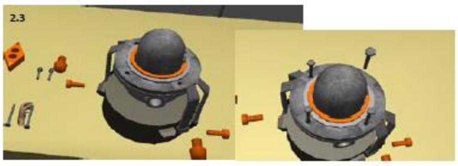
Appendix 2 – Standard Operating Procedure training program.

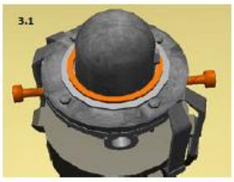
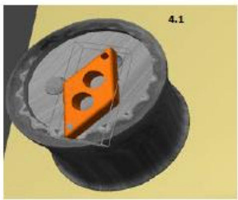
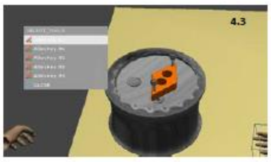
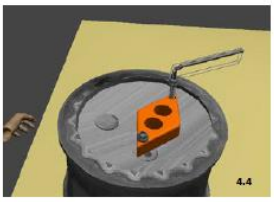


Appendix 2.1: Detecting and capturing the hand motion.

Appendix 2.2: Standard work elementary sheet for SOP training programme within the virtual reality system.

	Standard Operation			SWES ID		
				Date	Rev Level	
Seq#	Work Sequence Description	Symbol	Cycle time	Picture, sketch….		
1	**Fitting the washer and spherical part to the chassis** 1.1 Start the simulation program for the standard operation by pressing the menu button located on the right hand controller. Select the "Start". 1.2 Turn on the light, press the menu button on the right hand controller, select "light" and then "Turn light on". 1.3 With the right hand controller, grasp the ring and lift it of the table. Align it above the chassis thread. Once the ring is getting close enough to the thread, press the action button of the same hand controller and position it into the chassis. 1.4 With the right hand controller, grasp the washer and lift it of the table. Align it above the chassis and bring it closer to the age of the chassis. Once the washer is getting close enough to the age of the chassis, press the action button of the right hand controller and position it into the chassis. 1.5 With the left hand controller, pick up the spherical object and lift it of the table. With the right hand controller, grasp the rod part and lift it of the table, at the same level as the spherical object. 1.6 With the left hand controller, rotate 90 degree the spherical object in such a way that the spherical part get vertical to the table. 1.7 With the right hand controller, hold the rod and bring it close to the concentric entry of the spherical object. Press the action button of the right hand controller to position the rod inside of the spherical object. 1.8 With the left hand controller, direct the spherical part toward the chassis and align it above the thread. Once the spherical object is getting close to the thread, press the action button of the left hand controller and position the entire object onto the chassis.	✚ ✚ ★		    		
Key point						
Reason	Problem will appear if the based is not secured on the work bench					

2	**Assemblying of the chassis** 2.1 With the right hand controller, pick up the circlip and direct it toward the chassis in order to align it above the age of the chassis. Once the circlip is close enough to chassis, press the action button of the right hand controller to snap the circlip onto the chassis. 2.2 Secure the chassis with the arms. With the right hand controller, call the action menu and select "Secure parts", then select "Close arm". 2.3 With the right and left hand controller, pick up the M4 type screws two by two and place them onto the circlip by pressing the action button on each hand controller. 2.4 With the right hand controller, call the action menu and select "Tools". Then select the M4 type screwdriver. Bring the allen key above once of the M4 type screw and as soon as the allen key is touching the screw, use the action button of the right hand controller to fix the screw onto the chassis. Repeat the same action with the other M4 type screws. 2.5 At the end of the process, replace the allen key back on the shadow board at its correct place. Once the allen key is getting close to its place use the action button and place the tool.	✚ ✚ ★ ★ ● ➡		   	
Key point					
Reason					

3	**Fixing the upper part to the chassis.** 3.1 With the left and right controller, pick up the two M8 type bolt and place them onto the chassis. Once the bolts are getting close enough to the concentry entry of the chassi, press the action button on each hand controller to place the bolts. 3.2 With the right hand controller, rotate the entire chassis. Call the action menu, select "Rotation holder" and then "rotate". 3.3 With the left and right controller, pick up the two M9 type bolts and place them onto the chassis. Once the bolts are getting close enough to the concentry entry of the chassi, press the action button on each hand controller to place the bolts. 3.4 With the right hand controller call the action menu and then select the right type of allen key depending on the bolt. Bring the tool close enough to the bolt and then press the action button to fix the bolt onto the chassis. Replace the tool on the shadow board. With the same hand controller select "Rotation holder" and then "rotate". Repeat the same procedure until all the M8 and M9 type bolts are fixed onto the chassis.	✚ ★ ★ ★ ●		    	
Key point					
Reason					
4	**Mount the guide holes on to the first cover of the filter** 4.1 With the left hand controller, pick up the polygonal object and lift it of the table. Align it on top of the cylindrical object and as soon as it gets close to its top, use the action button to place the polygonal object. 4.2 With the right and left hand controller pick up the M3 types screws at the same time and align them on top of the polygonal object. Once they get close to the concentry entry of the polygonal object, press the action buttons of the hand controller at the same time in order to place the screws. 4.3 With the right hand controller, call the action menu, select "Tools" and then select M3 type screwdriver. Direct the allen key toward one of the M3 type screws and once the tool is in contact with the object, press the action button to fix the screw onto the cylindrical object. Repeat the same actions for the other screw.	★ ★ ● ➡		   	
Key point					
Reason					

5	**fixe the main part of the cover to the filter** 5.1 With both hand pick up the cylindrical object and align it on top of the chassis. Bring it close to the chassis and then press the action button of the right hand controller to fix the cylindrical object.	★ ★			
Key point					
Reason					
6	**fixe cover to the filter to the chassis** 6.1 With both hand controller pick up the cover and align it above the entire assembly product. As soon as the cover is close to the assembly, press the action button of the right hand controller and fixe the cover to the entire product.	★ ★ ➡		 	
		Total CT			

People		Velocity	➡	Role:	Role:	Role:	Role:	Operator:
Quality	★	Cost	●	Signature:	Signature:	Signature:	Signature:	

Appendix 2.3: Experiment 1

Sequence	Attributes	Value
2	People (%)	0
	Quality (%)	9.8
	Velocity (%)	6.542
1	People (%)	0
	Quality (%)	13.64
	Velocity (%)	20
4	People (%)	0
	Quality (%)	13.134
	Velocity (%)	5.3
3	People (%)	0
	Quality (%)	16.7
	Velocity (%)	34
5	People (%)	0
	Quality (%)	14.34
	Velocity (%)	20
6	People (%)	0
	Quality (%)	12.6
	Velocity (%)	53
End of Simulation	Processing time (min)	32.42

Appendix 2.4: Experiment 2

Sequence	Attributes	Value
2	People (%)	11.5
	Quality (%)	17.3
	Velocity (%)	21.56
1	People (%)	7.6
	Quality (%)	13.6
	Velocity (%)	16.18
4	People (%)	40.3
	Quality (%)	15.6
	Velocity (%)	34.56
3	People (%)	16.67
	Quality (%)	11.16
	Velocity (%)	9.7
5	People (%)	45.6
	Quality (%)	25.7
	Velocity (%)	12.5
6	People (%)	37.06
	Quality (%)	21.31
	Velocity (%)	36.7
End of Simulation	Processing time (min)	29.354

Appendix 2.5: Experiment 3

Sequence	Attributes	Value
1	People (%)	0
	Quality (%)	34.1
	Velocity (%)	17.5
2	People (%)	0
	Quality (%)	25.65
	Velocity (%)	16.18
3	People (%)	0
	Quality (%)	24.6
	Velocity (%)	9.1
4	People (%)	0
	Quality (%)	37.1
	Velocity (%)	11.7
5	People (%)	0
	Quality (%)	26.7
	Velocity (%)	34.1
6	People (%)	0
	Quality (%)	24.78
	Velocity (%)	64.7
End of Simulation	Processing time (min)	28.46

Appendix 2.6: Experiment 4

Sequence	Attributes	Value
1	People (%)	24.5
	Quality (%)	65.1
	Velocity (%)	22.5
2	People (%)	36.5
	Quality (%)	34.36
	Velocity (%)	40.17
3	People (%)	37.5
	Quality (%)	27.15
	Velocity (%)	38.75
4	People (%)	38.6
	Quality (%)	37.1
	Velocity (%)	50.01
5	People (%)	47.6
	Quality (%)	36.17
	Velocity (%)	47.01
6	People (%)	47.6
	Quality (%)	36.17
	Velocity (%)	60.2
End of Simulation	Processing time (min)	26.46

Appendix 2.7: Experiment 5

Sequence	Attributes	Value
1	People (%)	0
	Quality (%)	35.4
	Velocity (%)	6.25
2	People (%)	0
	Quality (%)	47.125
	Velocity (%)	20.35
3	People (%)	0
	Quality (%)	38.548
	Velocity (%)	7.56
4	People (%)	0
	Quality (%)	51.34
	Velocity (%)	19.18
5	People (%)	0
	Quality (%)	18.76
	Velocity (%)	20.1
6	People (%)	0
	Quality (%)	25.1
	Velocity (%)	28.15
End of Simulation	Processing time (min)	30.13

Appendix 2.8: Experiment 6

Sequence	Attributes	Value
1	People (%)	38.5
	Quality (%)	35.1
	Velocity (%)	37.1
2	People (%)	25.5
	Quality (%)	46.7
	Velocity (%)	19.1
	Cost (%)	
3	People (%)	21.25
	Quality (%)	35.4
	Velocity (%)	21.73
4	People (%)	31.4
	Quality (%)	50.34
	Velocity (%)	42.14
5	People (%)	25.1
	Quality (%)	16.7
	Velocity (%)	38.71
6	People (%)	37.25
	Quality (%)	41.9
	Velocity (%)	44.71
End of Simulation	Processing time (min)	25.1634

Appendix 2.9: Experiment 7

Sequence	Attributes	Value
1	People (%)	0
	Quality (%)	67
	Velocity (%)	50.45
2	People (%)	0
	Quality (%)	63.625
	Velocity (%)	55.31
3	People (%)	0
	Quality (%)	73.51
	Velocity (%)	39.51
4	People (%)	0
	Quality (%)	67
	Velocity (%)	65.15
5	People (%)	0
	Quality (%)	87.51
	Velocity (%)	55.1
6	People (%)	0
	Quality (%)	93.56
	Velocity (%)	84.16
End of Simulation	Processing time (min)	24.1634

Appendix 2.10: Experiment 8

Sequence	Attributes	Value
1	People (%)	13.5
	Quality (%)	67
	Velocity (%)	50.45
2	People (%)	26.45
	Quality (%)	63.625
	Velocity (%)	65.31
3	People (%)	44.51
	Quality (%)	73.51
	Velocity (%)	39.51
4	People (%)	68.73
	Quality (%)	67
	Velocity (%)	75.15
5	People (%)	41.51
	Quality (%)	87.51
	Velocity (%)	85.1
6	People (%)	44.8
	Quality (%)	93.56
	Velocity (%)	84.16
End of Simulation	Processing time (min)	16.49

Appendix 2.11: Experiment 9

Sequence	Attributes	Value
2	People (%)	52.5
	Quality (%)	28
	Velocity (%)	36.68
1	People (%)	43.124
	Quality (%)	37.5
	Velocity (%)	26.4
3	People (%)	54.3
	Quality (%)	56.625
	Velocity (%)	16.625
5	People (%)	61.236
	Quality (%)	13
	Velocity (%)	27
6	People (%)	73.165
	Quality (%)	19
	Velocity (%)	37
End of Simulation	Processing time (min)	28.42

Appendix 2.12: Experiment 10

Sequence	Attributes	Value
2	People (%)	83.5
	Quality (%)	25.1
	Velocity (%)	21.54
1	People (%)	79.6
	Quality (%)	19.6
	Velocity (%)	19.8
3	People (%)	82.51
	Quality (%)	16.7
	Velocity (%)	28.9
4	People (%)	78.73
	Quality (%)	32.6
	Velocity (%)	15.7
5	People (%)	81.51
	Quality (%)	34.9
	Velocity (%)	34.9
6	People (%)	94.8
	Quality (%)	44.7
	Velocity (%)	44.7
End of Simulation	Processing time (min)	25.12

Appendix 2.13: Experiment 11

Sequence	Attributes	Value
1	People (%)	53.5
	Quality (%)	34.2
	Velocity (%)	17.5
2	People (%)	37.6
	Quality (%)	33.9
	Velocity (%)	19.8
3	People (%)	47.36
	Quality (%)	29.87
	Velocity (%)	16.78
4	People (%)	48.73
	Quality (%)	29.7
	Velocity (%)	15.7
5	People (%)	58.4
	Quality (%)	40.9
	Velocity (%)	34.9
6	People (%)	62.5
	Quality (%)	44.7
	Velocity (%)	44.7
End of Simulation	Processing time (min)	23.46

Appendix 2.14: Experiment 12

Sequence	Attributes	Value
1	People (%)	83.4
	Quality (%)	67.9
	Velocity (%)	56.7
2	People (%)	89.67
	Quality (%)	49.64
	Velocity (%)	59.7
3	People (%)	93.4
	Quality (%)	52.34
	Velocity (%)	65.2
4	People (%)	84.6
	Quality (%)	34.1
	Velocity (%)	48.76
5	People (%)	91.6
	Quality (%)	43.1
	Velocity (%)	50.19
6	People (%)	84.6
	Quality (%)	49.5
	Velocity (%)	66.3
End of Simulation	Processing time (min)	17.46

Appendix 2.15: Experiment 13

Sequence	Attributes	Value
1	People (%)	61.5
	Quality (%)	47.9
	Velocity (%)	36.7
2	People (%)	53.2
	Quality (%)	49.64
	Velocity (%)	29.7
3	People (%)	48.4
	Quality (%)	35.34
	Velocity (%)	41.2
4	People (%)	62.14
	Quality (%)	58.6
	Velocity (%)	38.76
5	People (%)	63.98
	Quality (%)	53.1
	Velocity (%)	50.19
6	People (%)	69.3
	Quality (%)	47.5
	Velocity (%)	65.36
End of Simulation	Processing time (min)	23.59

Appendix 2.16: Experiment 14

Sequence	Attributes	Value
1	People (%)	79.25
	Quality (%)	59.5
	Velocity (%)	73
2	People (%)	77.9
	Quality (%)	41.6
	Velocity (%)	69.7
3	People (%)	89.4
	Quality (%)	59.6
	Velocity (%)	66.97
4	People (%)	95.9
	Quality (%)	67.79
	Velocity (%)	50.97
5	People (%)	91.6
	Quality (%)	56.4
	Velocity (%)	60.16
6	People (%)	89.41
	Quality (%)	41.97
	Velocity (%)	71.24
End of Simulation	Processing time (min)	17.346

Appendix 2.17: Experiment 15

Sequence	Attributes	Value
1	People (%)	65.3
	Quality (%)	67
	Velocity (%)	76.31
2	People (%)	55.7
	Quality (%)	69.8
	Velocity (%)	59.7
3	People (%)	61.2
	Quality (%)	86.46
	Velocity (%)	63.4
4	People (%)	49.8
	Quality (%)	63.7
	Velocity (%)	67.98
5	People (%)	59.6
	Quality (%)	73.64
	Velocity (%)	69.4
6	People (%)	65.5
	Quality (%)	67
	Velocity (%)	64.3
End of Simulation	Processing time (min)	16.12349

Appendix 2.18: Experiment 16

Sequence	Attributes	Value
1	People (%)	92.5
	Quality (%)	87
	Velocity (%)	86.4
2	People (%)	93.124
	Quality (%)	89.625
	Velocity (%)	64.3
3	People (%)	94.3
	Quality (%)	83.5
	Velocity (%)	83.4
4	People (%)	93.236
	Quality (%)	73.4
	Velocity (%)	76.3
5	People (%)	93.6
	Quality (%)	89.7
	Velocity (%)	84.6
6	People (%)	91.6
	Quality (%)	89.3
	Velocity (%)	83.6
End of Simulation	Processing time (min)	15.324

Appendix 2.19: Analysis of data coming from the SOP training program.

```
void retrive(string Input, double precision, double Seclevel)//to add int index
{
  static int No_lines=0, Tool_No_lines=0;
  string Reading;
  static string prevarea;
  string currentarea;
  static string *indexarray, *Toolindexarray;
  char * value;
  string value1;
  bool fileOK,Tooluseswitch=false;
  static string Toolusedmemo;


  char *areaptr =(char*)malloc(sizeof(char) * (Input.length() + 1));
  strcpy(areaptr,Input.c_str());

 ///****************************test sequence
*************************/

  SequenceDetection(areaptr);
  Input1 =strtok(areaptr,"$");
  stringstream s1,s2,s3;
  string areastring,Compstring,Toolstring;
  s1<< Input1;
  s1>> areastring;
  areastring = areastring + ".txt";
  areastring=Refpath+"\\"+areastring;
/*****************************Read from
file*************************/

  if ( areastring!= prevarea)
     {
      frmfile.open(areastring);
      if (frmfile.is_open())
            {
             while (frmfile.is_open())
                  {
                       while (!frmfile.eof())
                                {
                                 getline(frmfile,Reading);
                                 No_lines++;
                     if (Reading.find_first_not_of ("Tool") == string::npos)
                       Tool_No_lines++;
                                 }
                        frmfile.close();
                        indexarray= new string[No_lines];
```

```
                        frmfile.open(areastring);
                        if (frmfile.is_open())
                          {
                           for (int i=0; i<No_lines;i++)
                                  {
                                   getline(frmfile,Reading);
                                   indexarray[i]= Reading;
                               }
                           frmfile.close();
                         }
               }
            prevarea= areastring;
           }
  decode (Input,false);
  for (int m=0; m<No_lines;m++)
      {
       char *valuecheck =(char*)malloc(sizeof(char) * (indexarray[m].length() +
1));
       strcpy(valuecheck,indexarray[m].c_str());
           if (toolcomp==true) value= component2;
           else      value= component1;
       s2<< value;
           s2>> value1;
           size_t found;
           string namecomponent=indexarray[m];
           found =namecomponent.find(value1);
            if (found!=string::npos)
               {
               cout<<"Found"<<endl;
               decode (indexarray[m],true);//parameter to the function
               menutoolDetection(indexarray[m], true);
               toolmenuActive=menutoolDetection(Input, false);
               if (toolmenuActive== true) break;
               }
        }

//
************************comparaison**************************//
  if (toolcomp==true)
     {      if ((currentfingerx-1<=refindex[0]) && (refindex[0]<=currentfingerx+1)
        && (currentfingery-1<=refindex[1]) && (refindex[1]<=currentfingery+1)
        && (currentfingerz-1<=refindex[2]) && (refindex[2]<=currentfingerz+1))
               {
           ToolPosition=1;
           return;
          }
        else if ((currentfingerx-2<=refindex[0]) &&
               (refindex[0]<=currentfingerx+2)  &&
```

```
            (currentfingery-2<=refindex[1]) &&
            (refindex[1]<=currentfingery+2) &&
            (currentfingerz-2<=refindex[2]) &&
            (refindex[2]<=currentfingerz+2))
               {
             ToolPosition=2;
             return;
            }
      else  return;
     }
  else  OrderOfAssembly= comindex-comfileindex;

/********************end of the process*****************///
}
```

Appendix 2.20: Function of decoding data coming from the virtual reality system.

```
void decodedata ()
{ stringstream ss;
  string chkstring;
  ss << chk;
  ss >> chkstring;

  string directoryPath= ReferencePathCapture+"\\";
  string name_ext =directoryPath +chkstring+".txt";
  chk2 =(char*)malloc(sizeof(char) * (name_ext.length() + 1));
  ptr1=strtok (NULL, "$");
  strcpy(chk2,name_ext.c_str());
  if (toggle==false)
     {
      outfile.open(chk2);
      outfile << ptr1<<endl;
      outfile.close();
     }
   if (toggle==true)
      {
           outfile.open(chk2,ios::app);
           outfile << ptr1<<endl;
       }
    outfile.close();
    toggle=true;
}
```

Appendix 2.21: Function of detection the sequence of assembly within the SOP training program.

```
void SequenceDetection(char *genArea)
{  int sizOfcomponent= strlen (genArea);
   int indicatorPourcent, indicatorAndSigne, indicatorMinusSigne;
   char *CurrentCom= new char [sizOfcomponent];
   char *CurrentComSelected= new char [sizOfcomponent];
   static int numberofSequence=0;
   string line;
   static string * SequenceMemory;
   static string memorysameseq;
   string cheminDeSauvegarde=Refpath+"\\";
   string cheminSaver=cheminDeSauvegarde+"Sequence.txt";

   bool stopper= false;
   bool tooldetec= false;
   int indAndMinus=0, indiceCom=0;
   int areaIndex, NewIndex=0;
   for (int e=0; e<sizOfcomponent; e++) if (genArea[e]== '%') stopper =true;


   if (stopper == false) return;
   for (int e=0; e<sizOfcomponent; e++) if (genArea[e]== '$')areaIndex=e;
   for (int e=areaIndex+1; e<sizOfcomponent; e++)
      {
       CurrentCom[NewIndex]=genArea[e];
       NewIndex++;
      }
   CurrentCom[NewIndex]='\0';

   if (sequenceSwitch==0)
    {
     sequenceSwitch++;
         ifstream myfile (cheminSaver);
         if (myfile.is_open())
           {
        while ( myfile.good() )
                    {
             getline (myfile,line);
                     numberofSequence++;
                     }
            }
          myfile.close();
          SequenceMemory= new string[numberofSequence];
          myfile.open(cheminSaver);
          if (myfile.is_open())
             {
```

```
          for (int i=0; i<numberofSequence; i++)
                   {
              getline (myfile,line);
                     SequenceMemory[i]=line;
                     }
              }
           myfile.close();
      }

for  (int i=0;i<strlen(CurrentCom);i++)
    {
     if (CurrentCom[i]== '%')
           {
         indicatorPourcent=i;
         break;
        }
      }
 for (int i=0;i<strlen(CurrentCom);i++)
    {
     if(CurrentCom[i]=='&')
          {
       indicatorAndSigne=i;
       indAndMinus=1;
       break;
       }
     else indAndMinus=2;
     }
  switch (indAndMinus)
      {
       case 1:   for (int i=indicatorPourcent+1; i<indicatorAndSigne; i++)
                          {
                 CurrentComSelected[indiceCom]= CurrentCom[i];
                            indiceCom++;
                           }
                      break;
            case 2:  for (int i=indicatorPourcent+1; i<strlen(CurrentCom); i++)
                           {
                 CurrentComSelected[indiceCom]= CurrentCom[i];
                        indiceCom++;
                            }
                          break;
       }
 CurrentComSelected[indiceCom]='\0';
 stringstream convert;
 string strCom;
 convert << CurrentComSelected;
 convert >> strCom;
 for (int m=0; m<numberofSequence; m++)
```

```
      {int q;
           char* charSequence=(char*)malloc(sizeof(char) *
(SequenceMemory[m].length() + 1));
       strcpy(charSequence,SequenceMemory[m].c_str());
           for (int i=0; i<strlen(charSequence);i++) if (charSequence[i]=='&')  q=i;
   string strsequence= SequenceMemory[m].substr(0,q);
   stringstream conv;
   conv<< charSequence;
   conv>>strsequence;
   if (strCom== strsequence)
      {
       if (memorysameseq!=strCom)
          {
           SeqNumber= m;
               memorysameseq=strCom;
               SequenceMemory[m]='\0';
               return;
              }
       }
  }
}
```

Appendix 2.22: Tool detection function within the SOP training program.

```
bool menutoolDetection(string info, bool Memory)
{   int preindex=0,secindex=0, index=0;
    char * actionMenuCurrent;
    string transition;
    static string Memoir;

    char *currentdata =(char*)malloc(sizeof(char) * (info.length() + 1));
    strcpy(currentdata,info.c_str());
    int taille=strlen(currentdata);


    for (int i=0; i<strlen(currentdata); i++)
            {
        if (currentdata[i]=='(') preindex=i;
            else if (currentdata[i]==')') secindex=i;
            }
    actionMenuCurrent= new char[secindex-preindex];

    for (int i=preindex+1; i<secindex; i++)
        {
        actionMenuCurrent[index]=currentdata[i];
        index++;
        }

    actionMenuCurrent[index]='\0';
    stringstream ss;
    ss<<actionMenuCurrent;
    ss>>transition;
    if (Memory== true)
          {
        Memoir= transition;
        return 0;
       }
    else if (transition== Memoir) return true;
    else return false;
}
```

Appendix 2.23: Connection with the virtual reality training program.

```
DWORD WINAPI  SendrequestSOP(void * number2)
{ int count=0;
  SOCKET listenSocket, connectSocket, i;
  static unsigned short int listenPort;
  int clientAddressLength;
  struct sockaddr_in clientAddress, serverAddress;
  char line[LINE_ARRAY_SIZE];
  static bool synchroConnect= false;
 if(synchroConnect== false)
 {  listenPort = 30;
    WSADATA wsaData;
    int wsaret=WSAStartup(0x101,&wsaData);
  // Create socket for listening for client connection requests.
    listenSocket = socket(AF_INET, SOCK_STREAM, 0);
    if (listenSocket == INVALID_SOCKET)
      {cerr << "cannot create listen socket " << listenSocket << " \n";
       system("pause");
           synchroConnect= false;
      }
     serverAddress.sin_family = AF_INET;
     serverAddress.sin_addr.s_addr = htonl(INADDR_ANY);
     serverAddress.sin_port = htons(listenPort);

     if (bind(listenSocket,
     (struct sockaddr *) &serverAddress,sizeof(serverAddress)) < 0)
       {
        cerr << "cannot bind socket";
        synchroConnect= false;
       }
     listen(listenSocket, 5);
     clientAddressLength = sizeof(clientAddress);
    connectSocket = accept(listenSocket,
                       (struct sockaddr *) &clientAddress,
                       &clientAddressLength);
    if (connectSocket < 0)
      { cerr << "cannot accept connection ";
        synchroConnect= false;
      }
    synchroConnect= true;
  }
  memset(line, 0x0, LINE_ARRAY_SIZE);
//////////////////////////////////////////////////////////////////////////////////
  while (1)
          { if(disconnexion==true) break;
        char * writable = new char[SOP_Synchroniz.size() + 1];
        std::copy(SOP_Synchroniz.begin(), SOP_Synchroniz.end(), writable);
```

```
        writable[SOP_Synchroniz.size()] = '\0';
    // Send converted line back to client.
        if (send(connectSocket, writable, strlen(writable) + 1, 0) < 0)
          cerr << "Error: cannot send modified data";
          memset(line, 0x0, LINE_ARRAY_SIZE);  // set line to all zeroes
              Sleep(30);
          }
           return 0;
}
```

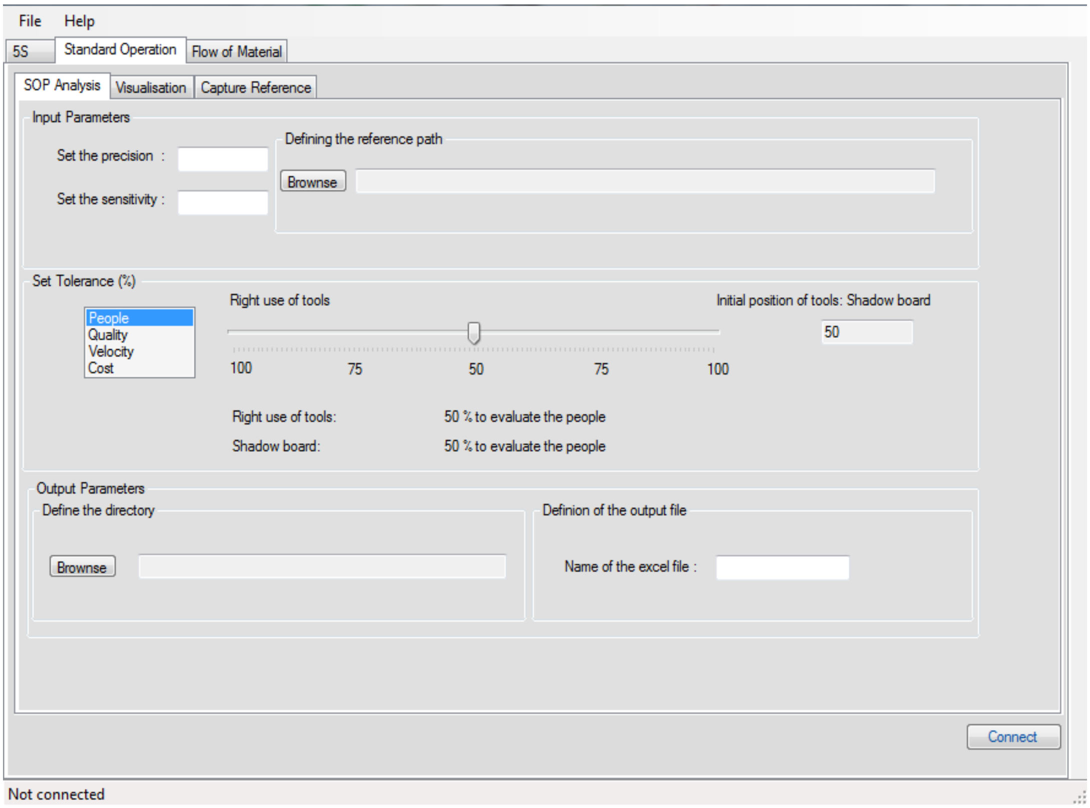
Appendix 2.24: Real time display function for SOP performance measures.

```
void Resultdisplayer()
   {
    int count=0, count2=0, count3=0;
    double faux=0, vrai=0,toolmenu=0;
    int * errorMemo=NULL;
    int * more_error;

    int * AssemblyMemo=NULL;
    int * more_assembly;

    int * ToolsPositionMemo;
    int * more_tool;
    bool * ToolMenuMemo;
    bool * more_ToolMenuMemo;

    int ToolPosition, OrderOfAssembly;
    int Average_Error=0, Average_Order=0, Average_Tool=0;
    int Sum_Error, Sum_Order, Sum_Tool;
    String ^ Coefquality,^Coefvelocity,^Coefpeople,^Coefcost;
    bool synchronisation;
    static bool toolutilisation;
    double meanquality,meanvelocity, meancost,meanpeople;

    double Motion=0, Order=0, Tool=0, People=0;
    while (1)
           {
        if (connexion==1) break;
           else Sleep(50);
           }
    while (1)
        {
         Sum_Error=0;
             Sum_Order=0;
             Sum_Tool=0;
```

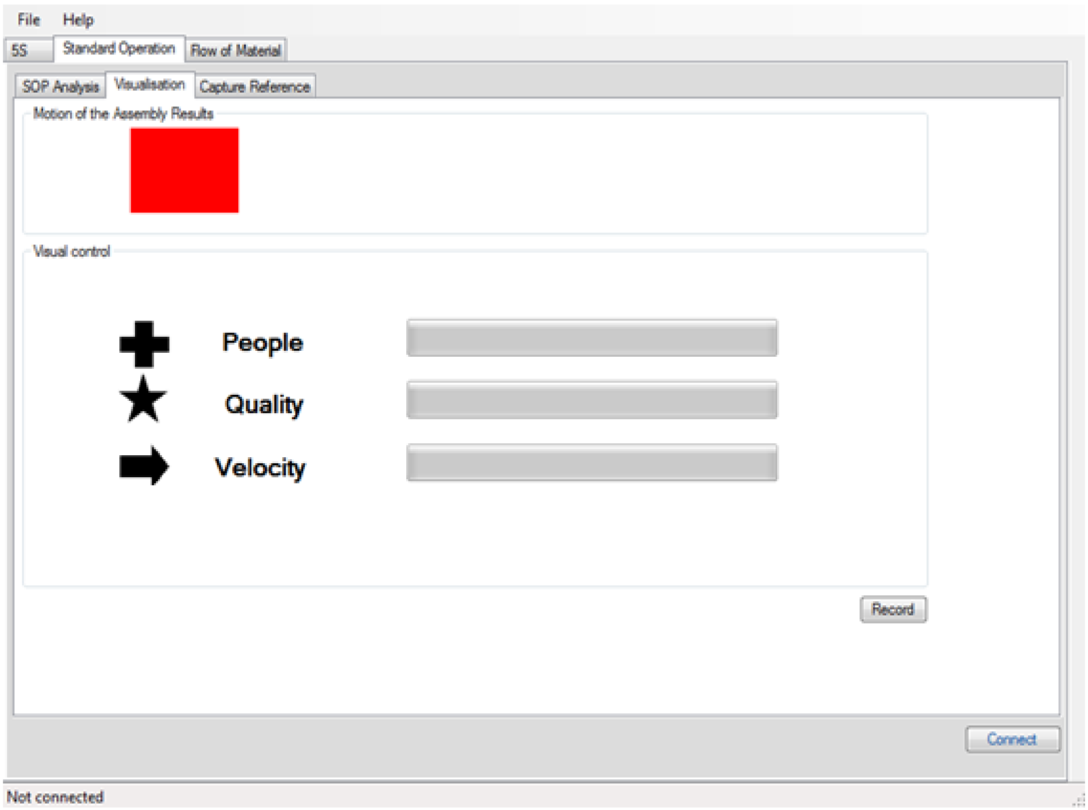
```
            bool toolcomp= false, comcomp=false;
            if (closeProgram==true) break;
            error=FF->ThreadfunctionCommunication();
            count++;
            more_error = (int*) realloc (errorMemo, count * sizeof(int));
            if (more_error!=NULL)
           {
            errorMemo=more_error;
                   errorMemo[count-1]=error;
           }
        if(Disconnexion==true) break;
            synchronisation=FF->Synchronizationfct();
            comcomp=FF->toolcompfct(false);
        if (synchronisation == true &&  comcomp== true)
              {
                   toolcomp=FF->toolcompfct(true);
                   if (toolcomp== true)
                      {
                       ToolPosition=FF->ReturnfunctionOrderToolPos();
                       count2++;
                       more_tool = (int*) realloc (ToolsPositionMemo, count2 *
              sizeof(int));
              if (more_tool!=NULL)
                 {
                 ToolsPositionMemo=more_tool;
                     ToolsPositionMemo[count2-1]=ToolPosition;
                         }
                      }
         else
           {
            OrderOfAssembly=FF->ReturnfunctionOrderToolPos();
            toolutilisation=FF->ReturnfunctionToolMenu();
            count3++;
            more_assembly= (int*) realloc (AssemblyMemo, count3 * sizeof(int));
         if (more_assembly!=NULL)
           {
            AssemblyMemo=more_assembly;
            AssemblyMemo[count3-1]=OrderOfAssembly;
           }
            more_ToolMenuMemo= (bool*) realloc (ToolMenuMemo, count3 *
sizeof(bool));

         if (more_ToolMenuMemo!=NULL)
           {
            ToolMenuMemo=more_ToolMenuMemo;
            ToolMenuMemo[count3-1]=toolutilisation;
           }
        }
```

```
  if (error== 1) panel1->BackColor = System::Drawing::Color::Green;
  else if (error== 2) panel1->BackColor= System::Drawing::Color::Orange;
  else panel1->BackColor=System::Drawing::Color::Red;

/***************************************************************
****/
  SeqNumber= FF->ReturnSeqNumber();
  if (currentSeqNum!= SeqNumber)
    {
     currentSeqNum= SeqNumber;
///**** Error Memo  ****///
     for (int i=0; i<count; i++) Sum_Error+=errorMemo[i];
     Average_Error= Sum_Error/count;
         if (toolcomp== true)
          {
      for (int i=0; i<count2; i++)
             {
          Sum_Tool+=ToolsPositionMemo[i];
              verage_Tool= Sum_Tool/count2;
             }
         }
   else
     {for ( int i=0; i<count3; i++)
             {
          Sum_Order+=AssemblyMemo[i];
                   Average_Order= Sum_Order/count3;
              }
          }
////****** Mapping  ******//////
          Motion = (Average_Error*100)/3;
         if (toolcomp== true)Tool = (Average_Tool*100)/3;
     else {
             if (abs (Average_Order)==0) Order=100;
             else if ((abs (Average_Order)>0) && (abs (Average_Order)<1))
Order= 87;
             else if (abs (Average_Order)==1)  Order =75;
             else if ((abs (Average_Order)>1)&&(abs (Average_Order)<2))
Order=62;
             else if (abs (Average_Order) == 2) Order = 50;
             else if ((abs (Average_Order)>2)&&(abs (Average_Order)<3))
Order=37;
         else if (abs (Average_Order)==3) Order= 25;
             else if ((abs (Average_Order)>3)&&(abs (Average_Order)<4))
Order=12;
         else if (abs (Average_Order)==4) Order =0;
             else Order =0;
            for (int i=0; i<sizeof(ToolMenuMemo); i++)
```

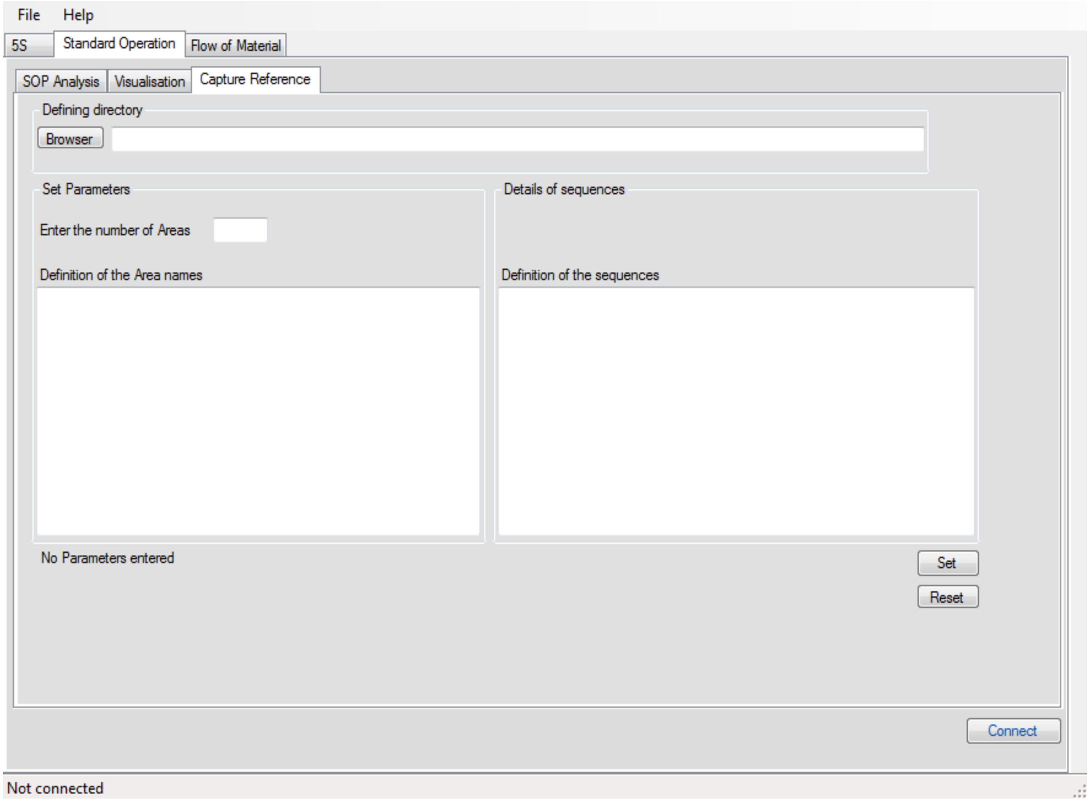
```
            {
          if (ToolMenuMemo[i]== true) vrai++;
            else faux++;
            }
          toolmenu= vrai/(vrai+faux);
        }
////*********Definition of the Metrics*******/////
    double Coefquality_d=   arrayselection[1];
    double Coefvelocity_d=  arrayselection[2];
       double Coefpeople_d= arrayselection[0];
    double Coefcost_d=  arrayselection[3];

       double Coefquality_dBar= 100-arrayselection[1];
    double Coefvelocity_dBar= 100-arrayselection[2];
       double Coefpeople_dBar= 100-arrayselection[0];
       double Coefcost_dBar= 100-arrayselection[3];
////////// End //////////////////
quality =   (Motion+toolmenu)*(Coefquality_dBar/100) +
(Order*(Coefquality_d/100));
velocity= ( Tool*(Coefvelocity_dBar/100))-
((Motion+toolmenu)*(Coefvelocity_d/100));
                                    cost= (Motion*(Coefcost_dBar/100))-
(Order*(Coefcost_d/100));
people= (Tool*(Coefpeople_dBar/100))-(toolmenu*(Coefpeople_d/100));

               quality= abs(quality);
               velocity= abs(velocity);
               cost= abs(cost);
               people=abs(people);
////********* displaying *********/////
Invoke(gcnew new_foo_delegate2(this,&Form1::ProgressBarfct));
if (DataCollectionfeu== true) Invoke(gcnew
new_foo_delegate2(this,&Form1::DataCollection));
// Set back the memory to initial value (Zero)
       count=0;
       count2=0;
       count3=0;
       }
       Sleep (20);
    }
  }
}
```



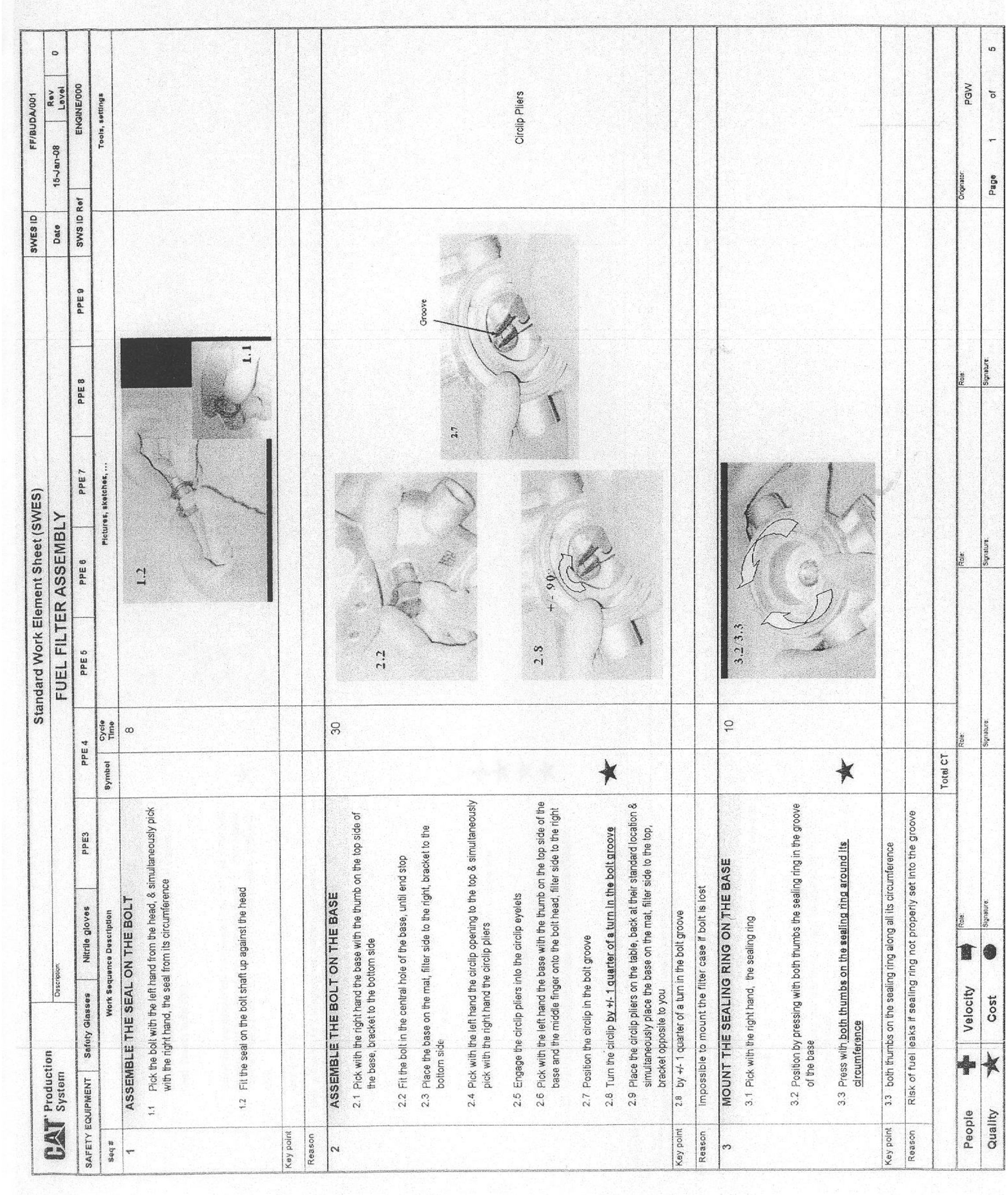
Appendix 2.25: Setup interface for visualising SOP data in real time.



Appendix 2.26: Data visualisation interface of the SOP training program.



Appendix 2.27: Creating a reference file for the SOP training program.



CAT Production System	Standard Work Element Sheet (SWES)	SWES ID	FF/BUDA/001		
	Description: FUEL FILTER ASSEMBLY	Date	15-Jan-08	Rev Level	0

SAFETY EQUIPMENT	Safety Glasses	Nitrile gloves	PPE3	PPE 4	PPE 5	PPE 6	PPE 7	PPE 8	PPE 9	SWS ID Ref	ENGINE/000

Seq #	Work Sequence Description	Symbol	Cycle Time	Pictures, sketches, ...	Tools, settings
1	**ASSEMBLE THE SEAL ON THE BOLT**		8	1.2 / 1.1	
	1.1 Pick the bolt with the left hand from the head, & simultaneously pick with the right hand, the seal from its circumference				
	1.2 Fit the seal on the bolt shaft up against the head				
Key point					
Reason					
2	**ASSEMBLE THE BOLT ON THE BASE**		30	2.2 / 2.8 +/- 90 / 2.7 Groove	Circlip Pliers
	2.1 Pick with the right hand the base with the thumb on the top side of the base, bracket to the bottom side				
	2.2 Fit the bolt in the central hole of the base, until end stop				
	2.3 Place the base on the mat, filter side to the right, bracket to the bottom side				
	2.4 Pick with the left hand the circlip opening to the top & simultaneously pick with the right hand the circlip pliers				
	2.5 Engage the circlip pliers into the circlip eyelets				
	2.6 Pick with the left hand the base with the thumb on the top side of the base and the middle finger onto the bolt head, filter side to the right				
	2.7 Position the circlip in the bolt groove				
	2.8 Turn the circlip **by +/- 1 quarter of a turn in the bolt groove**	★			
	2.9 Place the circlip pliers on the table, back at their standard location & simultaneously place the base on the mat, filter side to the top, bracket opposite to you				
Key point	2.8 by +/- 1 quarter of a turn in the bolt groove				
Reason	Impossible to mount the filter case if bolt is lost				
3	**MOUNT THE SEALING RING ON THE BASE**		10	3.2/3.3	
	3.1 Pick with the right hand, the sealing ring				
	3.2 Position by pressing with both thumbs the sealing ring in the groove of the base				
	3.3 Press with **both thumbs on the sealing ring around its circumference**	★			
Key point	3.3 both thumbs on the sealing ring along all its circumference				
Reason	Risk of fuel leaks if sealing ring not properly set into the groove				
		Total CT			

People ✚	Velocity	Role:	Role:	Role:	Role:	Originator:	PGW
Quality ★	Cost ●	Signature:	Signature:	Signature:	Signature:	Page 1 of 5	

Appendix 2.28: SWES of the fuel filter assembly used in Caterpillar production system

Appendix 2.29: Instructions provided for trainees during the experimentations of the SOP

Standard Operating Procedure (SOP) training program

Simulation 1

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Standard Operating Procedure (SOP) training program

Simulation 2

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

<u>Tips:</u>

- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

Standard Operating Procedure (SOP) training program

Simulation 3

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.

Standard Operating Procedure (SOP) training program

Simulation 4

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.

- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

Standard Operating Procedure (SOP) training program

Simulation 5

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

<u>Tips:</u>

- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.

Standard Operating Procedure (SOP) training program

Simulation 6

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.
- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

Standard Operating Procedure (SOP) training program

Simulation 7

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After getting the induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help make sure to pause the simulation beforehand.

Tips:

- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.
- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.

Standard Operating Procedure (SOP) training program

Simulation 8

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

<u>Tips:</u>

- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.
- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.
- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

Standard Operating Procedure (SOP) training program

Simulation 9

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.

Standard Operating Procedure (SOP) training program

Simulation 10

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.
- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

Standard Operating Procedure (SOP) training program

Simulation 11

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

<u>Tips:</u>

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.
- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.

Standard Operating Procedure (SOP) training program

Simulation 12

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.
- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.
- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

Standard Operating Procedure (SOP) training program

Simulation 13

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.
- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.

Standard Operating Procedure (SOP) training program

Simulation 14

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

<u>Tips:</u>

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.
- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.
- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

Standard Operating Procedure (SOP) training program

Simulation 15

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.
- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.
- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.

Standard Operating Procedure (SOP) training program

Simulation 16

Aim: The objective of the training program is to assemble a fuel filter as efficiently as possible in order to obtain high results at the end of the simulation.

After receiving an induction on how to use the virtual reality equipment, please start the simulation run. Use the action button on your right hand in order to start the simulation. If you require help, make sure to pause the simulation beforehand.

Tips:

- Health and safety is one of the important elements of SOP; make sure you consult the work sequence description of the Standard Work Element Sheet (SWES) and action the health and safety element when required.
- Before assembling the virtual item, consult the Standard Work Element Sheet (SWES) and carefully follow the hand motion described in the picture section. Please follow the trainer/assessor guidance.
- Before starting the simulation, please consult the Standard Work Element Sheet (SWES) and ensure you familiarise yourself with the sequence of assembly. It can be found in the first column of the SWES. Each sequence is successfully completed once all steps of the assembly have been carried out up until the end.
- Sets of tool are defined in the decision-making menu. To access them, press the action button - this is located on your right hand controller - and select the appropriate tool for the right process.

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